The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
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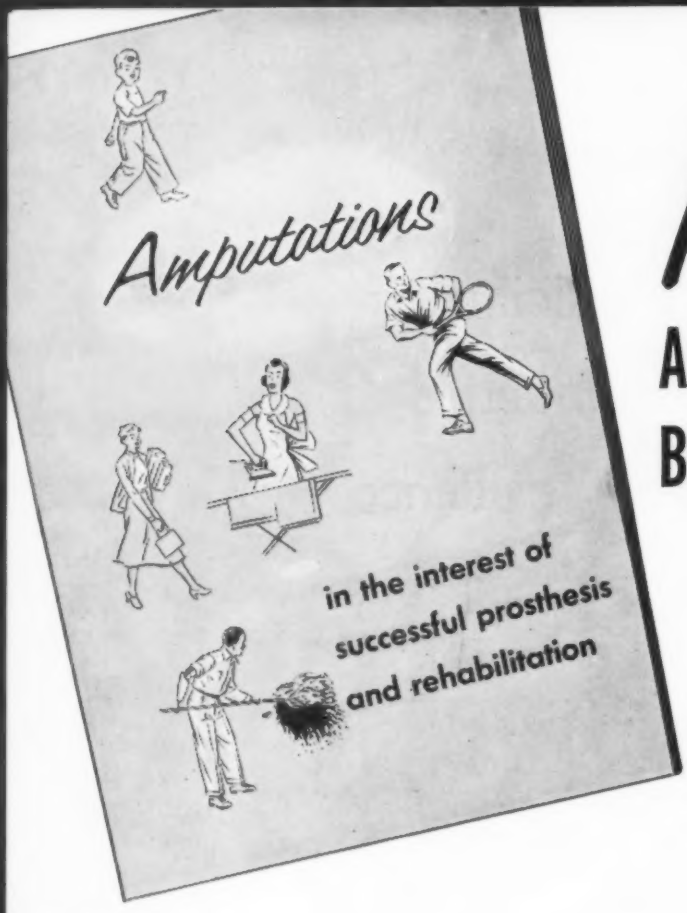

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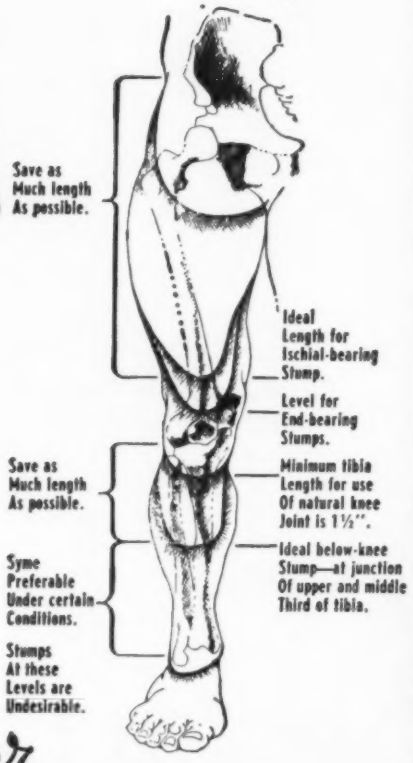

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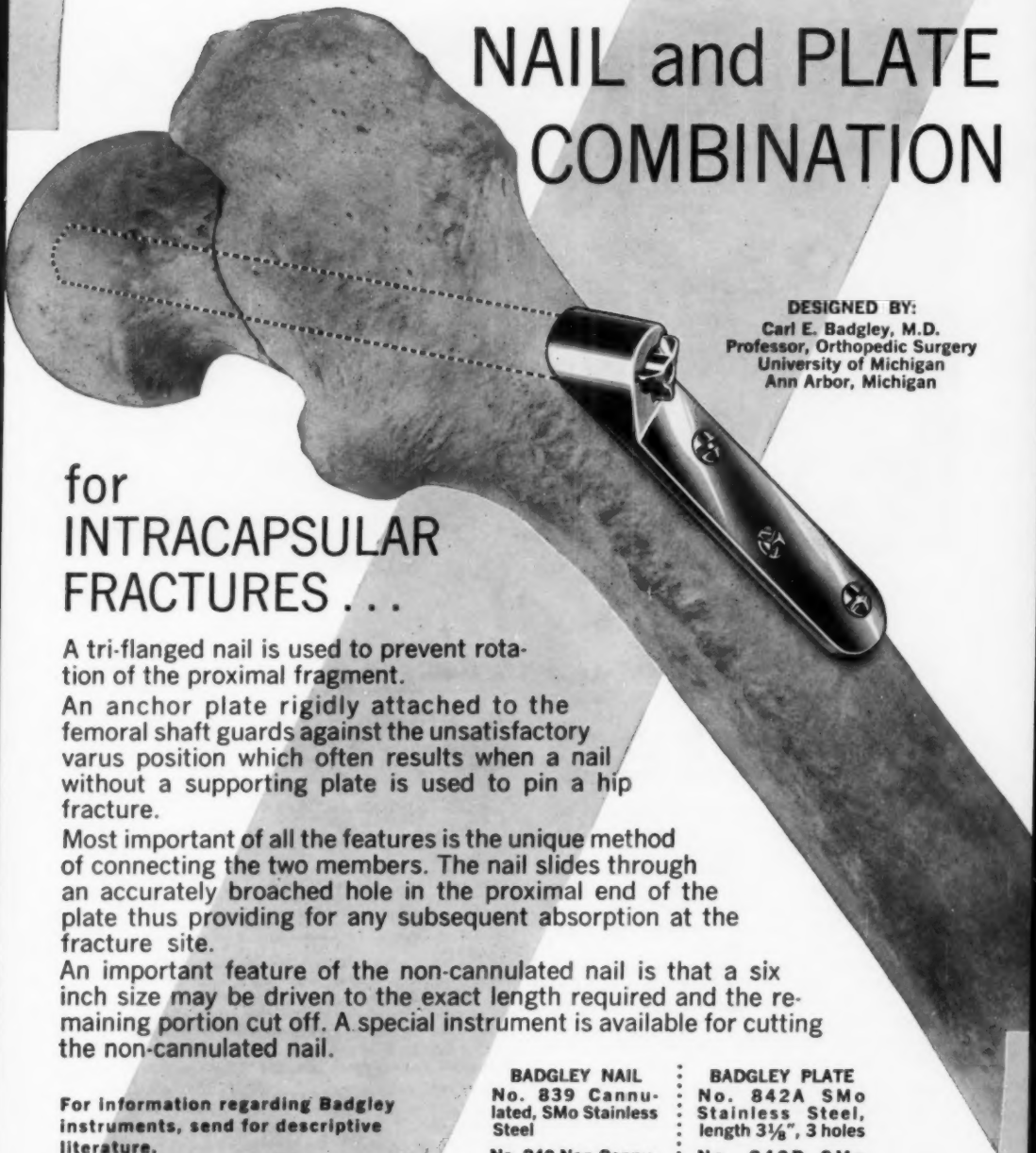

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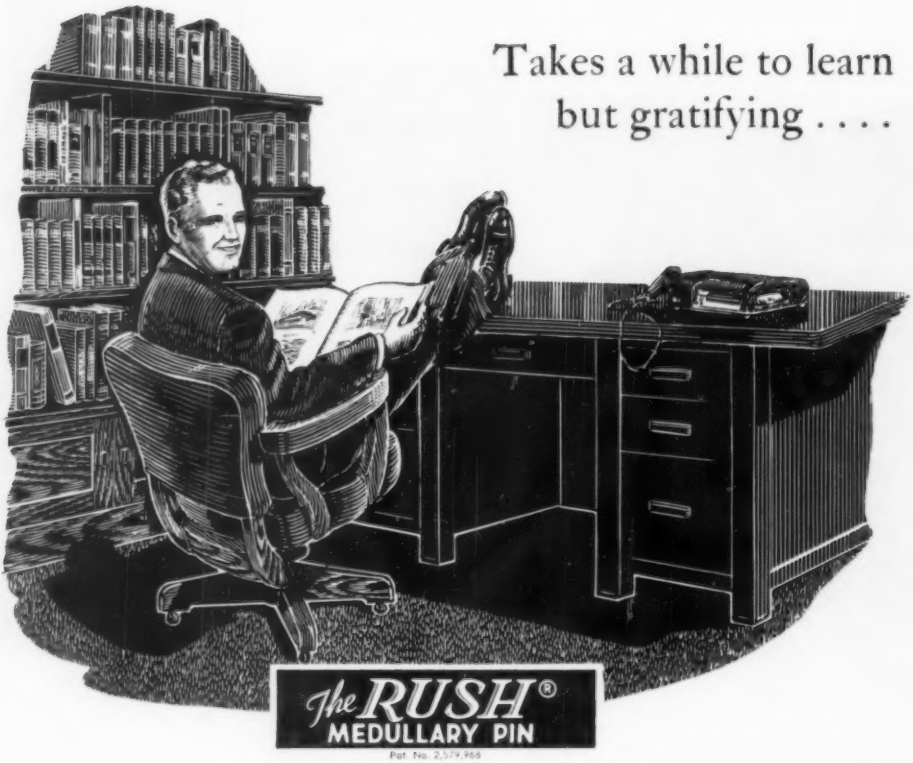

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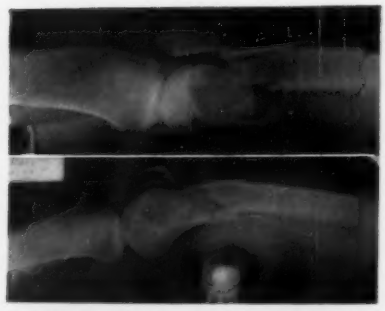

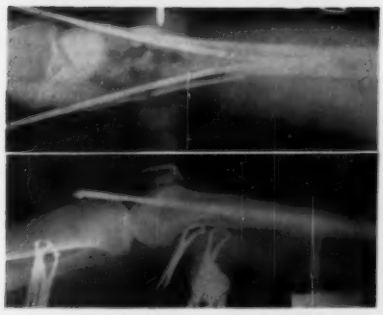

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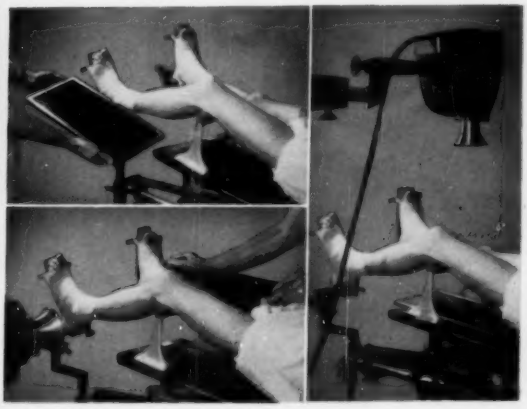
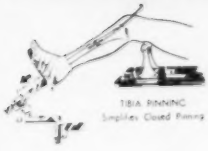


X-Rays shown are actual operating room films showing technic of CLOSED PINNING of comminuted supra-condylar fracture of femur in elderly female. Note shadow of RUSH COUNTERSUPPORT.



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But his fears and doubts may seriously complicate your plans.

'Dexamyl' can help you prepare him mentally and emotionally—both for surgery and for an uneventful postoperative course. 'Dexamyl' smoothly and subtly relieves both depression and anxiety. It will help him to view his problems in proper perspective. It will help to restore a normal sense of optimism, cheerfulness and well-being.

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Child Life
SHOES

adaptable
in any of these directions.

It is always easier to insert wedges into shoes that have been made with this purpose in mind, than to attempt to wedge conventional shoes. It is less difficult for the shoemaker, more resultful for the doctor, and less expensive for the patient.

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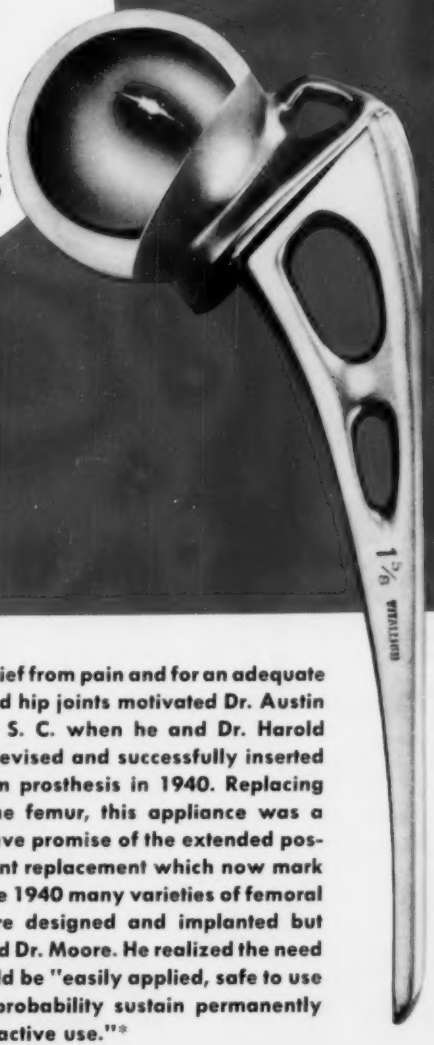
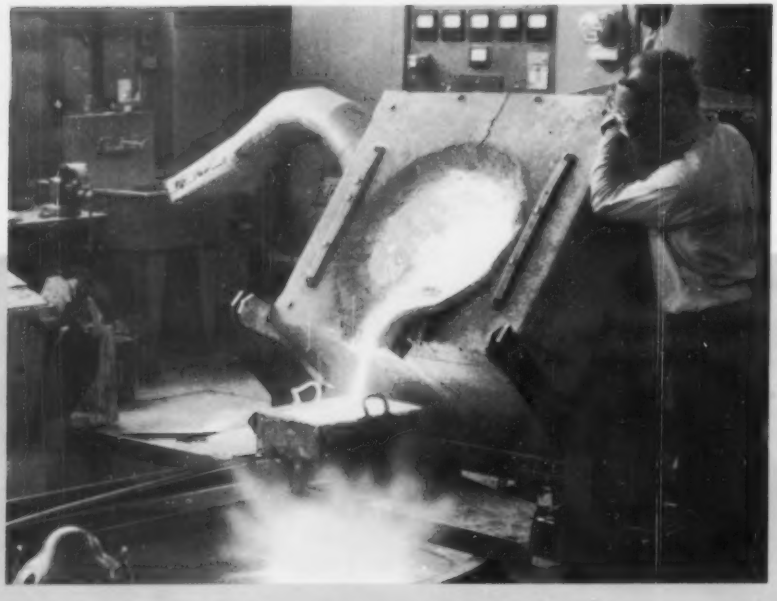
EXTENDED POSSIBILITIES...

THE AUSTIN MOORE VITALLIUM® Self-Locking HIP PROSTHESIS



The long-felt need for relief from pain and for an adequate replacement for diseased hip joints motivated Dr. Austin T. Moore of Columbia, S. C. when he and Dr. Harold Bohlman of Baltimore devised and successfully inserted a 12-inch long Vitallium prosthesis in 1940. Replacing the upper portion of the femur, this appliance was a pioneering effort that gave promise of the extended possibilities in bone and joint replacement which now mark orthopedic surgery. Since 1940 many varieties of femoral head replacements were designed and implanted but none completely satisfied Dr. Moore. He realized the need for a prosthesis that could be "easily applied, safe to use and that would in all probability sustain permanently the stress and strain of active use."*

QUALITY CONTROLLED FROM ALLOY MAKING



ALLOY POURING—Austenal manufactures its own alloy to insure the constant quality and uniform composition of Vitallium.

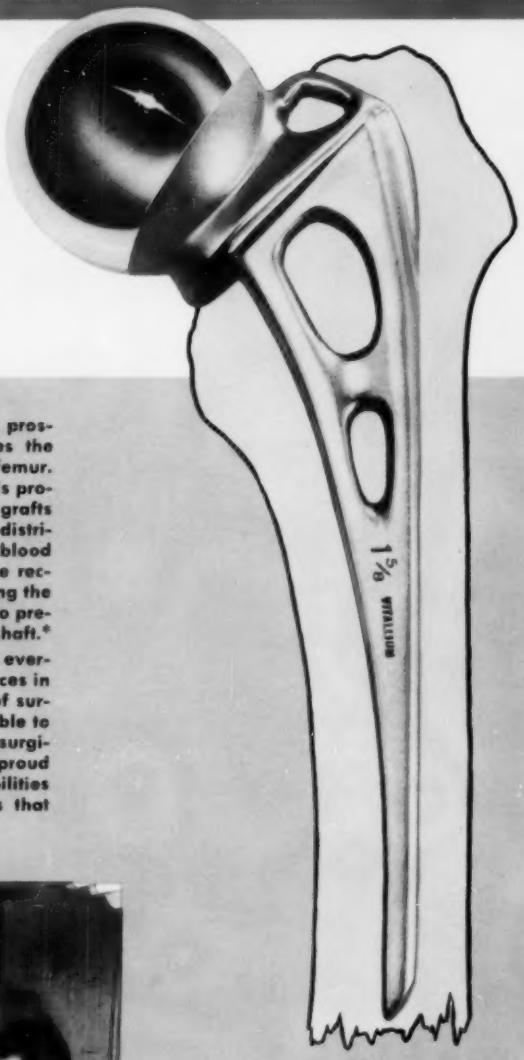
Designing and producing a hip prosthesis that would adequately meet the manifold requirements of tissue compatibility, ease of insertion and withstand the stresses to which it would be subjected presented many challenges which previously had not been encountered. Based on clinical experience, Dr. Moore knew that Vitallium passed the test of tissue compatibility. He then turned to the mechanical and design engineers. After consulting Dr. Robert Sumwalt, Dean of the University of South Carolina engineering school, Dr. Moore presented the problem to Austenal's research and development staff in New York. Here experienced engineers, metallurgists and technicians combined to contribute their knowledge to the problem. Dr. Moore's pilot model was subjected to extensive testing. Changes were made. Finally, the design was approved by Dr. Moore and a wax positive made, preparatory to casting.

Vitallium hip prostheses are made by the precision casting process. In all steps of production quality controls ensure rigid adherence to design and dimensional specifications. Controlled investment procedures coupled with alloy made by Austenal contribute to the fundamental soundness of the castings and to precision dimensions. All hip appliances are checked by a 250,000 volt X-ray for soundness of internal structure and by Zyglo†, the fluorescent penetrant for surface inspection. Only after requisite finishing and polishing operations and final inspection are any Vitallium prostheses released for applications in surgery.

†Tr. Mk. of Magnaf[illegible] Corp.

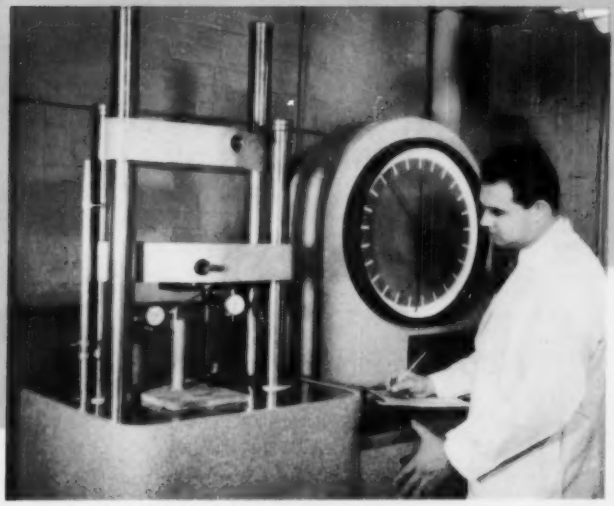
VITALLIUM®

TO FINISHED PRODUCT



The Moore-type Vitallium femoral head prosthesis as developed closely approximates the normal anatomical configurations of the femur. It fits either the left or right side. The stem is provided with fenestrations to allow for bone grafts which lock the prosthesis in place, widen distribution of stress and provide channels for blood supply to the upper part of the femur. The rectangular design of the stem and the fin along the outer surface were specified by Dr. Moore to prevent rotation of the prosthesis in the femoral shaft.*

This prosthesis is another example of the ever-extending possibilities of Vitallium appliances in surgical applications. Through the efforts of surgeons like Dr. Moore, Austenal has been able to produce an ever-broadening line of quality surgical appliances and instruments. Austenal is proud to have taken part in extending these possibilities and bringing the surgeon better products that deserve his confidence.



UNIVERSAL TESTING MACHINE— For transverse bend testing, compressive load testing, and tensile testing of appliances and instruments.

*Moore, Austin T.: Metal Hip Joint, A New Self-Locking Vitallium Prosthe South. Med. Journ. 45: 1015-1019 (Nov. 1952).

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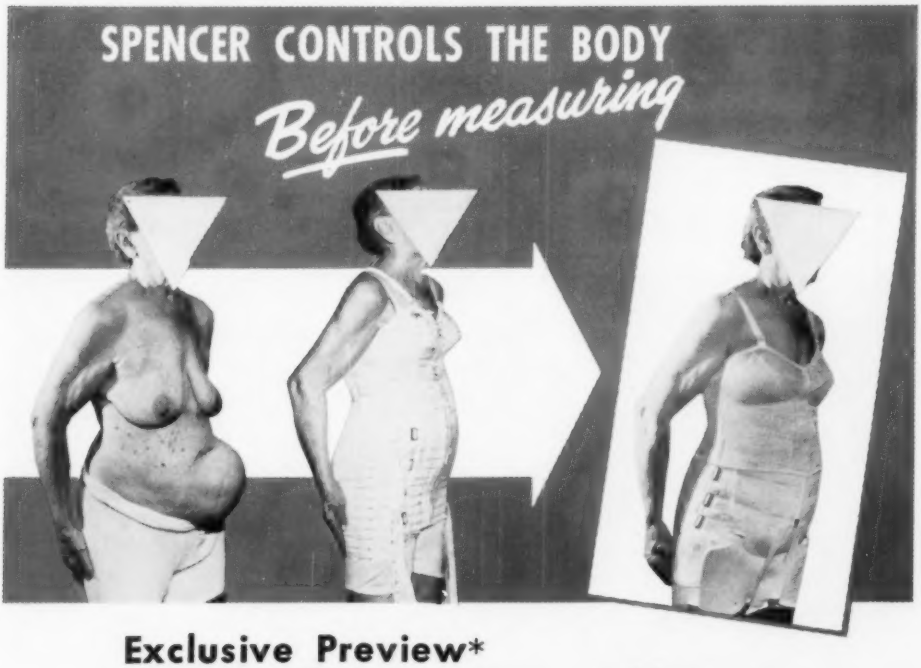

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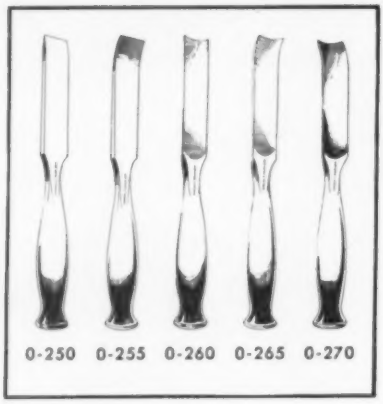

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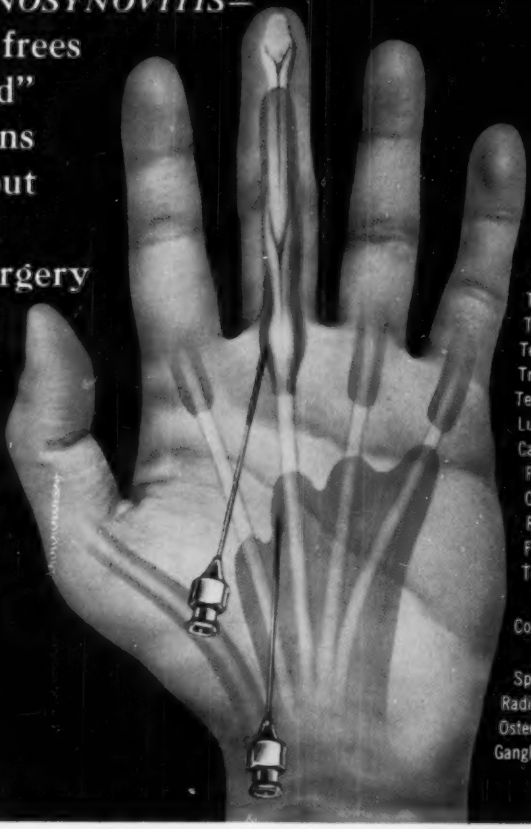

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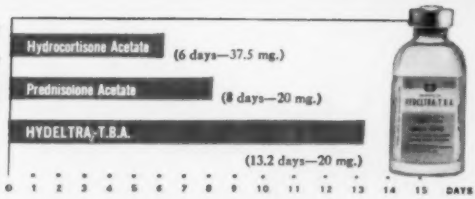
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*Reifenstein, E. C., Jr., in Harrison, T. R.: Principles of Internal Medicine, ed. 2, New York, The Blakiston Company, Inc., 1954, chap. 98, pp. 702, 703.

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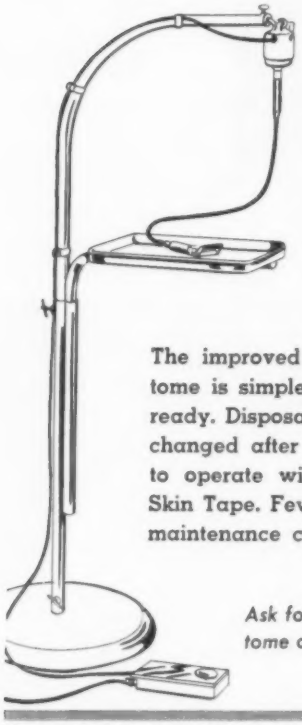

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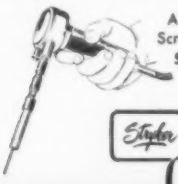

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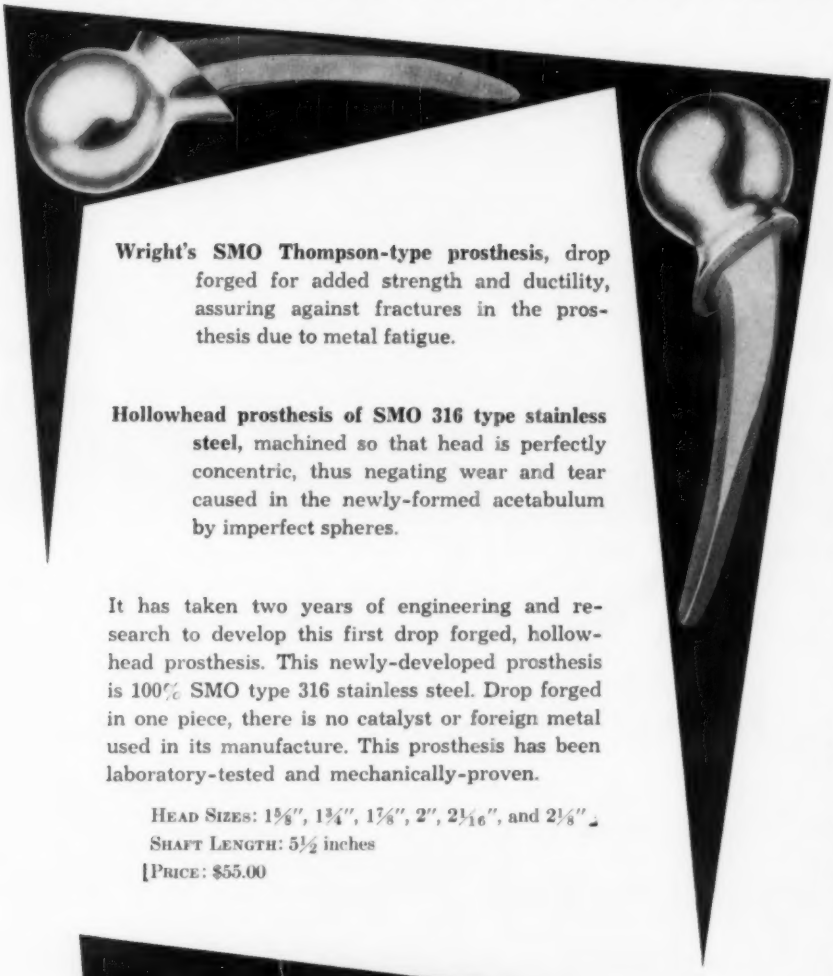

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Bibliography:
(1) Boone, J. D.; Muñoz, R., and Dillon, J. B.: Anesthesiology *17*:284, 1956. (2) Zima, O.; von Werder, F., and Hotovy, R.: Anaesthesist *3*:244, 1954. (3) Mersch, M. A.; Clarie, D'A., and Fitzpatrick, L. J.: J.M. Soc. New Jersey *53*:414, 1956. (4) Blake, M. W., and Perlman, P. L.: J. Pharmacol. & Exper. Therap. *117*:287, 1956. (5) Irwin, S.; Stagg, R. D.; Dunbar, E., and Govier, W. M.: J. Pharmacol. & Exper. Therap. *116*:317, 1956. (6) Ayd, F. J., Jr.: Neraval: A new anesthetic for electroconvulsive therapy, Paper presented at annual meet., Electroshock Research Association, Chicago, Illinois, April 29, 1956. (7) Reifferscheid, M., and Dietmann, K.: Deutsche med. Wchnschr. *79*:638, 1954. (8) Houde, J.; Hudon, F., and Jacques, A.: Neraval (methitural sodium), Paper presented at Meet., Canad. Anaesth. Soc., Quebec City, P. Q., May 5, 1956.

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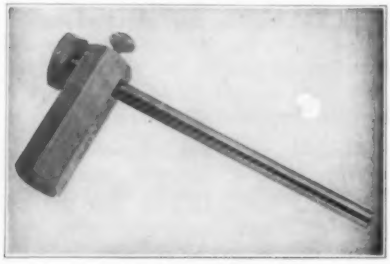

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The Journal of
Bone and Joint Surgery

American Volume

Experience in Reconstructive Surgery with Patients Having Respiratory Paralysis*

BY VERNON L. NICKEL, M.D., AND WILEY L. RENSHAW, M.D., LOS ANGELES, CALIFORNIA

From the Respiratory Center for Poliomyelitis †, Rancho Los Amigos Hospital, Hondo, California, and the Department of Orthopaedics, College of Medical Evangelists, Los Angeles

The lives of an increasing number of patients with respiratory paralysis are being saved because of revolutionary improvements in the mechanical and medical treatment of this condition. At the same time many of these patients are being denied the advantages of reconstructive surgery because the severity of their condition increases the hazards of this surgery.

This is particularly unfortunate because it is in the severely involved patient that function may be considerably increased by one or two elective procedures. Furthermore, in patients with progressive scoliosis and with severely paralyzed collapsing torsos, spine fusion will contribute to a longer life.

From March 1954 to March 1956, a total of 233 orthopaedic operations were performed at the Rancho Los Amigos Hospital ** — sixty-nine in the first year and 164 in the second year. In the group of patients operated upon in the first year, twenty required respiratory equipment during the early stages of the disease, but none required tracheotomy, none used equipment immediately before the operation, and none were transported to or from surgery in respiratory equipment. In the second group, 114 patients required respiratory equipment in the acute phase of the disease, twenty-six of these patients also requiring tracheotomy. In four additional patients tracheotomy was performed specifically as a preparation for spine fusion. Also in the second group twenty-seven patients used equipment preoperatively, thirteen were transported to surgery in respiratory equipment, thirty-six were brought from surgery in respiratory equipment, forty-eight used this equipment after the operation, and ten used the mechanical coughing device. The first group is fairly representative of the type of patient formerly considered eligible for orthopaedic surgery, while the second group emphasizes the severity of the respiratory involvement in patients now considered eligible for such surgery.

Chart I shows the percentage of vital capacity in these patients at the time of surgery. In the first group only four patients with a vital capacity of from 30 to 50 per cent were operated upon, whereas in the second group seventy-one patients with vital capacities of

* Read at the Annual Meeting of The American Orthopaedic Association, Banff, Alberta, Canada, June 21, 1956.

† The Respiratory Center is aided by an annual grant from The National Foundation for Infantile Paralysis, Inc.

** In a subsequent paper a detailed description of preoperative care, anaesthesia management, and postoperative care will be given.

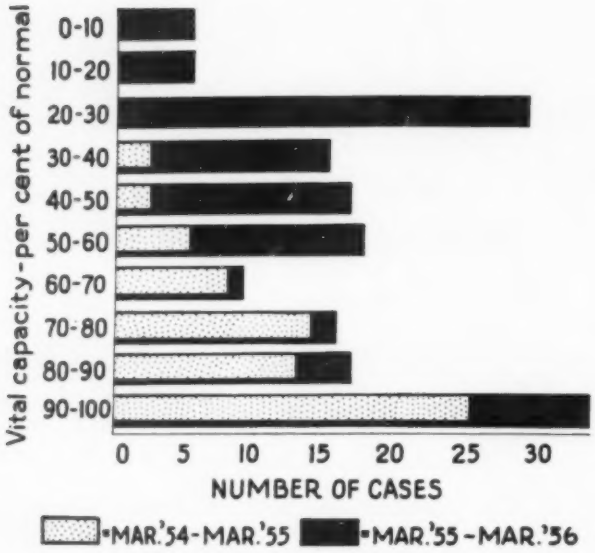

CHART I

from 0 to 50 per cent were operated upon. This indicates that the surgical risk in many of the patients in the second group was greater than that in any of the patients in the first group.

Generally speaking, all patients with a vital capacity of less than 30 per cent require respiratory equipment during surgery. Patients with a vital capacity of from 30 to 60 per cent may or may not need equipment, depending on their breathing pattern, while patients with a vital capacity of above 60 per cent usually do not need equipment unless the procedures result in fixed splinting from muscle spasm, as do spine fusion or abdominal-fascial transplant. The most significant fact demonstrated in Chart I is that whereas in the first group no patients with vital capacities of from 0 to 30 per cent were accepted as surgical risks, in the second group thirty-nine patients with vital capacities of from 0 to 30 per cent not only were accepted, but also were safely operated upon as a result of the use of respiratory equipment.

Table I illustrates the range of procedures carried out. Almost all of these operations were performed by residents in training at the Los Angeles County Hospital, under the immediate supervision of the Rancho Staff.

General anaesthesia was given. As a result of the use of standard techniques of intubation and manual control of respiration, administration of the anaesthesia was not a major problem. We believe that the use of local anaesthesia in these patients is contraindicated because of their emotional disturbances. The anaesthetists were residents in training at the Los Angeles County Hospital. During the period of premedication and during the first few days following the operation, the most critical observation is necessary. Adequate sedation can be safely given to patients who are using the mechanical breathing apparatus, if the loss of muscle mass in these patients is taken into consideration in determining the dosage of the sedation.

From our experience we feel that the following criteria form a safe basis for determining if a patient with respiratory paralysis is eligible for operation:

1. Availability of proper mechanical equipment and trained personnel. The tank respirator and positive-pressure apparatus, as well as the suction and coughing devices, are essential. At present this equipment and trained personnel are available in most areas,

TABLE I

CLASSIFICATION OF OPERATIONS

	March 1954 to March 1955	March 1955 to March 1956
Tendon transfer	32	63
Osteotomy	4	22
Arthrodesis	16	29
Spine fusion	3	25
Cervical-spine fusion	0	4
Abdominal fascial transplant	3	15
Miscellaneous	5	10

especially in the fifteen areas in which respiratory centers sponsored by The National Foundation for Infantile Paralysis are located.

2. Careful preoperative evaluation of the vital capacity and respiratory pattern of the patient as well as preoperative trial use of the equipment to be used during the operation.

COMPLICATIONS

From 1950, when the use of orthopaedic surgery was initiated at Rancho Los Amigos, to March 1956, a total of 339 orthopaedic operations were performed. In one patient moderately severe atelectasis occurred, but the condition improved immediately following the performance of tracheotomy and the placement of the patient in a tank respirator (if the patient had been operated upon at the time of writing, these measures would have been automatically carried out immediately after the surgery). In two cases mild to moderate atelectasis occurred. There were no deaths.

FIG. 1

A patient with a positive-pressure breathing apparatus following spine fusion.

Figure 1 shows a boy, seven years old, two days after the performance of spine fusion. In this operation the third cervical to the seventh thoracic vertebrae were fused (subsequently, in a second stage, the fusion was extended to the third lumbar vertebra). Tracheotomy was also performed electively prior to spine fusion, and the end of a positive-pressure apparatus was inserted in the opening. The photograph shows the child lying in a molded-plaster bed. He had severe paralysis of the torso with flail neck. He had good function of the lower extremities and some function of the upper extremities.

CONCLUSIONS

On the basis of this series it is felt that patients with severe respiratory paralysis can be given the benefits of reconstructive surgery without greater risk than is now thought suitable. It is our opinion that the techniques used in this surgery may be used in the treatment of other diseases, such as paralysis resulting from cervical-spine injury. Probably most important in our work has been the use of these techniques in procedures which result in considerable chest splinting and depressed respiration. We are impressed with the easier course of the patient following such procedures as thoracic-spine fusion when a respirator is used postoperatively, even if this equipment is not absolutely essential for the maintenance of life. Much to our surprise, the patients with the lower vital capacities have, as a whole, tolerated the procedures better than the patients with the higher vital capacities for whom respiratory equipment was not felt to be necessary. It is our opinion that the advisability of using mechanical respiratory aids in operations upon patients with decreased breathing function will come to be generally recognized, just as we now recognize the need to provide blood replacement during surgery rather than waiting until shock has occurred. The respirator which originally saved the patient's life now permits this patient to be operated upon.

Osteogenic Sarcoma

A Critical Analysis of 430 Cases *

BY MARK B. COVENTRY, M.D., AND DAVID C. DAHLIN, M.D., ROCHESTER, MINNESOTA

From the Section of Orthopaedic Surgery and the Section of Surgical Pathology, Mayo Clinic and Mayo Foundation †, Rochester

One of us (D. C. D.) has particularly studied the pathological nature of the bone tumors encountered at the Mayo Clinic from 1909 through December 1955. In the entire series of 2,276 pathologically verified tumors, there were 490 osteogenic sarcomata, 218 chondrosarcomata, fifty-eight fibrosarcomata, seventy reticulum-cell sarcomata, and 141 Ewing tumors. Osteogenic sarcoma has been encountered from two to eight times as often as these other common primary malignant tumors of bone. Only the incidence of myeloma (563 cases) surpassed that of osteogenic sarcoma. The purpose of this paper is to present the results of our study of the cases of osteogenic sarcoma.

We have defined osteogenic sarcoma as a malignant tumor of bone, the proliferating neoplastic cells of which produce osteoid. This definition avoids the unsettled controversy concerning the exact cell of origin of these tumors and is based on the recognizable products of the neoplasm. Osteoid production may be limited to small foci in the tumor. The main mass of the neoplasm may appear quite like fibrosarcoma or chondrosarcoma or it may be completely undifferentiated. Regardless of the predominant cell type, those tumors in which malignant cells produce osteoid (osteogenic sarcoma) have a similar age distribution, a similar localization, a similar strong tendency to metastasize, and hence a similar prognosis. This definition, therefore, has clinical usefulness.

Osteogenic sarcomata, thus defined, fall into three groups. Depending on the predominant differentiation observed microscopically in sections taken from various parts of the lesion, they are classified as osteoblastic, chondroblastic, or fibroblastic (Figs. 1, 2, and 3). Even with this classification it is necessary to be arbitrary in some cases. For example, one occasionally encounters a highly anaplastic bone tumor that produces no osteoid but is otherwise so similar in histological appearance to osteoid-producing tumors that the lesion logically must be classified as an osteoblastic sarcoma. Some tumors that otherwise appear to be unmixed fibrosarcomata contain foci of homogeneous, afibrillar, eosinophilic material that could be interpreted as hyalinized collagen. When such foci could not be differentiated with certainty from osteoid tissue, tumors containing them have been arbitrarily classed as fibroblastic osteogenic sarcomata. The usual member of this group, however, exhibits obvious formation of osteoid. One must be similarly arbitrary in regard to the occasional chondroblastic osteogenic sarcoma in which osteoid production is debatable; but, with few exceptions, it is possible to make a clear-cut differentiation between chondrosarcoma and chondroblastic osteogenic sarcoma. In the latter, the malignant cells, in at least some areas, show definite direct production of osteoid tissue unlike the secondary ossification of cartilage that is sometimes seen in chondrosarcoma.

Clinically, there are significant differences between chondrosarcoma and chondroblastic osteogenic sarcoma. Unmixed chondrosarcoma occurs at an older age (Chart I), has a predilection for different bones, has a much slower clinical evolution, and is much less prone to metastasize than is osteogenic sarcoma[8].

It is largely of didactic interest, however, to differentiate unmixed fibrosarcoma

* Read at the Annual Meeting of The American Orthopaedic Association, Banff, Alberta, Canada, June 21, 1956.

† The Mayo Foundation, Rochester, Minnesota, is a part of the Graduate School of the University of Minnesota.

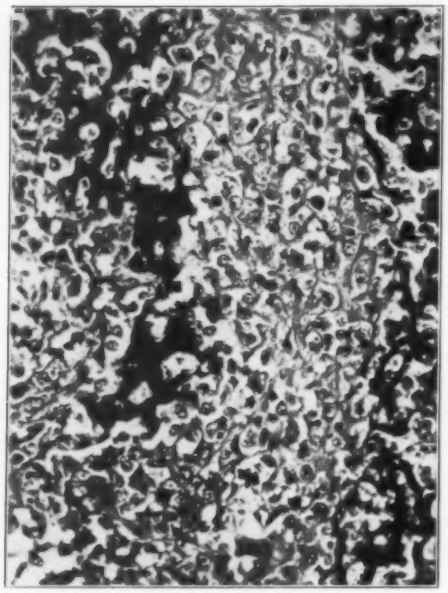

FIG. 1

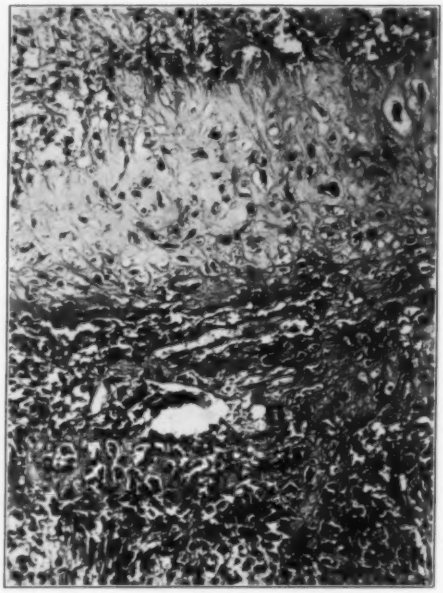

FIG. 2

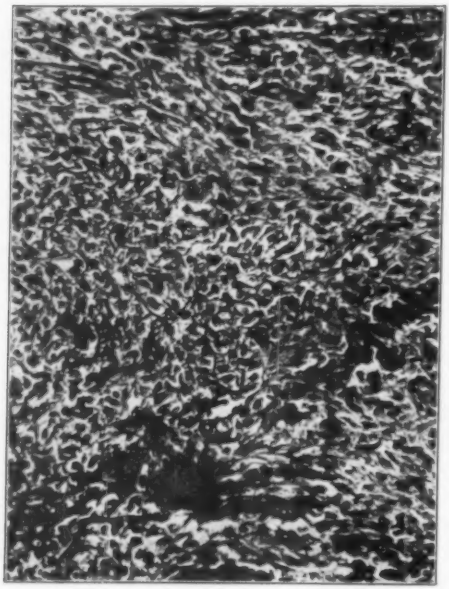

FIG. 3

Fig. 1: Osteoblastic osteogenic sarcoma with lacework of osteoid between malignant cells. Black zones indicate calcified osteoid tissue (hematoxylin and eosin, × 177).

Fig. 2: Chondroblastic osteogenic sarcoma showing large chondroid zones but with distinct osteoid network near the lower end of the picture (hematoxylin and eosin, × 91).

Fig. 3: Fibroblastic osteogenic sarcoma with osteoid production by the tumor cells in the lower margin of the picture (hematoxylin and eosin, × 153).

from osteogenic sarcoma. In our experience fibrosarcoma has a tendency to metastasize and has a prognosis very similar to that of osteogenic sarcoma [12].

Our classification does not employ many of the older subtypes of osteogenic sarcoma, such as the central, periosteal, sclerosing, and telangiectatic. It seems necessary, however, to recognize a special subtype of well differentiated osteosarcoma which is characteristically juxtacortical or parosteal in location and which has been confused with such entities as myositis ossificans [9, 10]. The twenty-one parosteal osteogenic sarcomata in this series are not included in the subsequent statistical data because of their indolent clinical evolution. They occur in a somewhat older age group and are characterized by a tendency to delayed recurrence or metastasis, in contrast to ordinary osteogenic sarcoma. Also, nineteen mandibular and twenty maxillary osteogenic sarcomata are not included in the data that follow because their location produces special clinical and therapeutic problems.

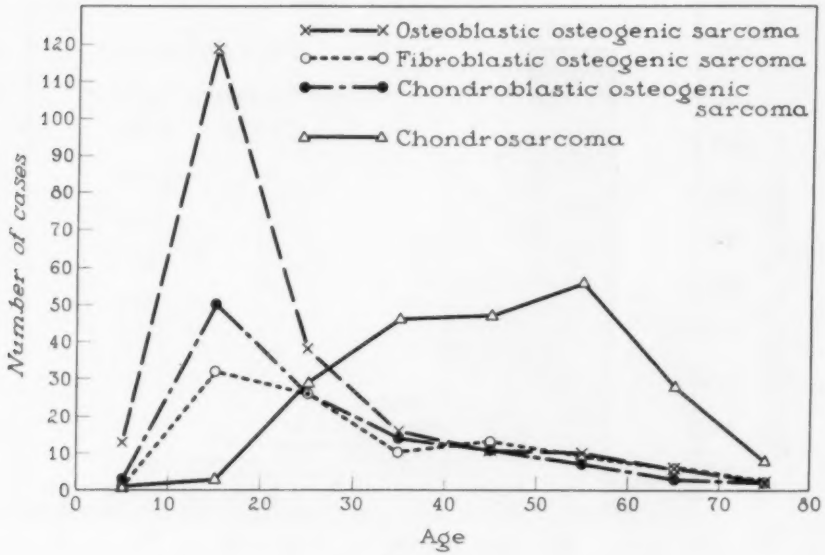

CHART I

Age distribution of patients with osteogenic sarcoma and of patients with chondrosarcoma. Note the increased incidence of chondrosarcoma in the older age groups.

Thus, there remain 430 cases of osteogenic sarcoma for study. Microscopic sections of tissue removed from the tumors were examined in each case, and the gross specimen was available and was studied in most cases. In addition, the clinical histories and operative notes were evaluated. Of the patients involved, 97 per cent were traced and follow-up data were obtained.

INCIDENCE

As mentioned previously, osteogenic sarcoma occurred more frequently than any other primary malignant tumor of bone, if myeloma is excluded. Meyerding stated in 1938 that about one per 4,000 patients who entered the Mayo Clinic had osteogenic sarcoma. Coley has estimated that the incidence of osteogenic sarcoma is one per 100,000 persons in the United States.

LOCATION

The distribution of the osteogenic sarcomata according to site of involvement is indicated in Figure 4. The metaphyseal end of the long bones was the most frequent location. More than 50 per cent of the tumors were about the knee, and only eight tumors were found in the hands and feet.

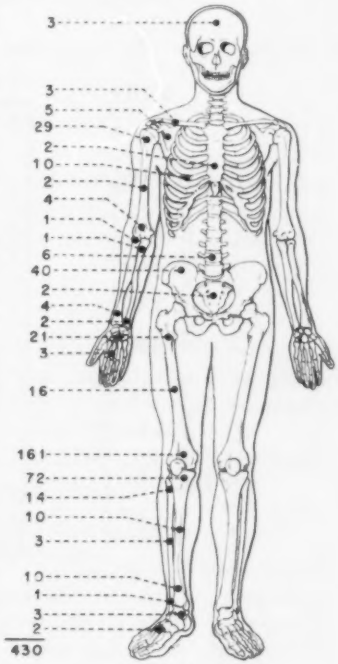

FIG. 4

Anatomical distribution of osteogenic sarcomata.

AGE AND SEX

The distribution according to the age of patient at the time osteogenic sarcoma occurred is given in Chart II. Although this disease can occur at any age, 46.9 per cent of the patients were in

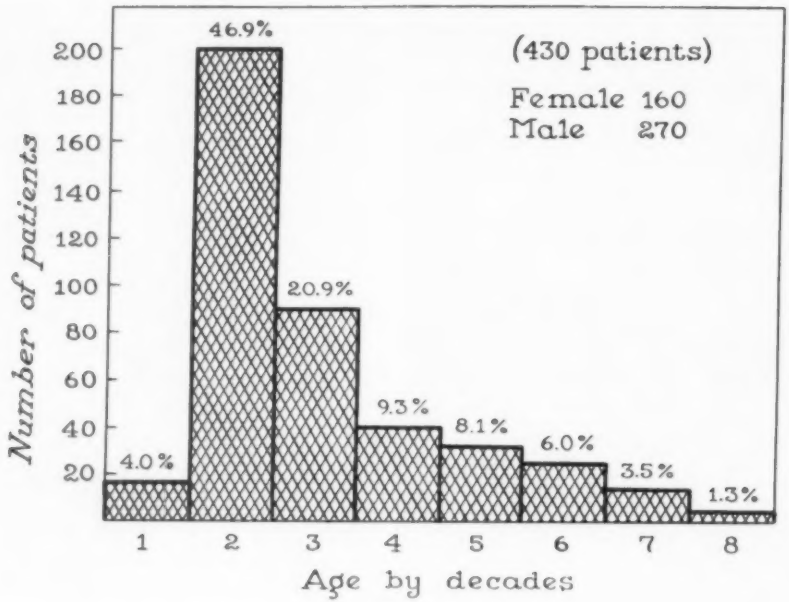

CHART II

Distribution of osteogenic sarcomata according to age and sex of patients.

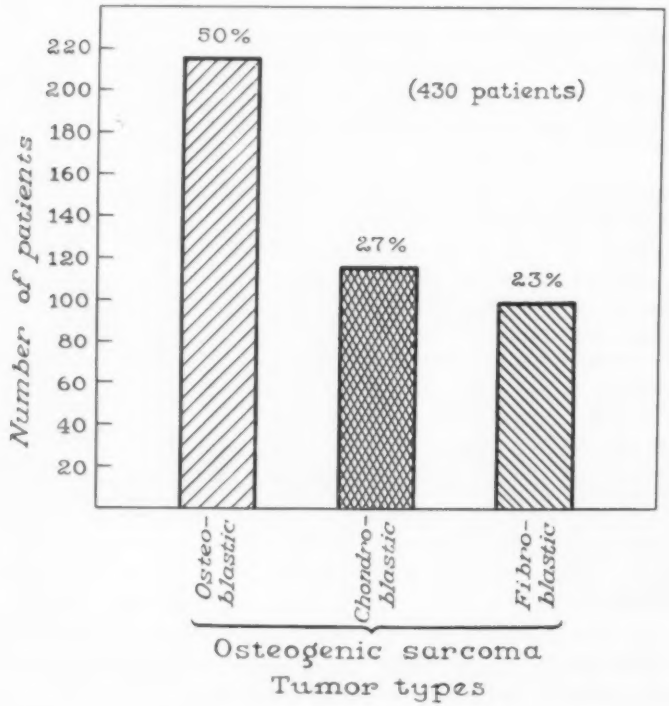

CHART III

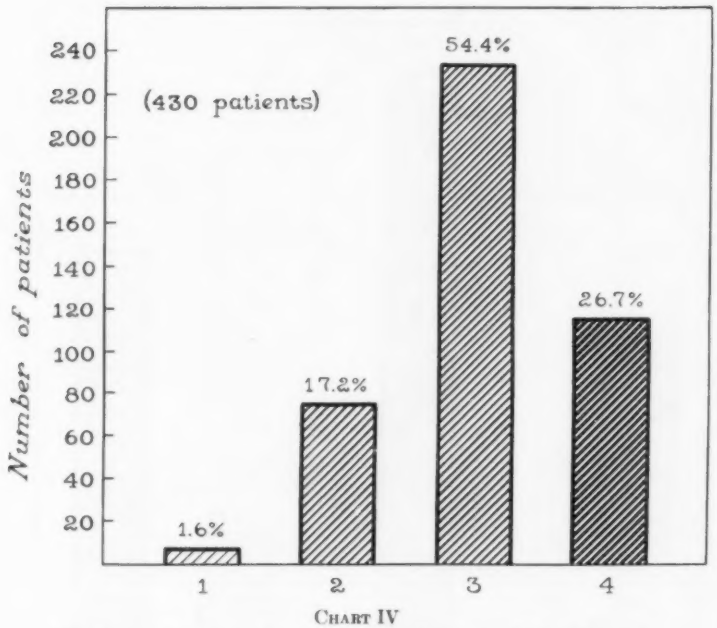

CHART IV

Distribution of osteogenic sarcomata according to grade of malignancy.

the age group ten through nineteen years. The youngest patient was four and a half years old, and none was more than eighty years of age.

Males constituted 62.8 per cent of the patients.

TYPE OF TUMOR

The distribution according to tumor type is illustrated in Chart III. Two hundred fifteen patients (50 per cent) had osteoblastic osteogenic sarcoma, 116 (27 per cent) had chondroblastic sarcoma, and ninety-nine (23 per cent) had fibroblastic sarcoma. Only seven of the 430 sarcomata were secondary to Paget's disease.

GRADE OF MALIGNANCY

The sarcomata were given a numerical grade (from 1 to 4, after the method of Broders) based on the degree of anaplasia. Features such as multinucleated malignant cells and atypical mitotic figures were counted as important evidence of anaplasia. In this way, about 81 per cent of the tumors were graded 3 or 4, and 19 per cent were graded 1 or 2. Only seven were graded 1. The largest group consisted of the tumors graded 3, representing 234 patients. The distribution by grade is illustrated in Chart IV.

RELATIONSHIP BETWEEN AGE AND GRADE OF MALIGNANCY

In order to study the relationship between the age of the patient and the grade of malignancy, the series was divided into two groups: those patients (217) who were less than twenty years of age and those (213) who were twenty years old or older. Each group was then subdivided into those with grade 1 or grade 2 lesions and those with grade 3 or grade 4 lesions. A definite relationship was found to exist between age and the grade of malignancy (Chart V). In the younger group of patients, 92.2 per cent were found to have grade 3 or grade 4 lesions as compared with 70 per cent with grade 3 or grade 4 lesions in the older group.

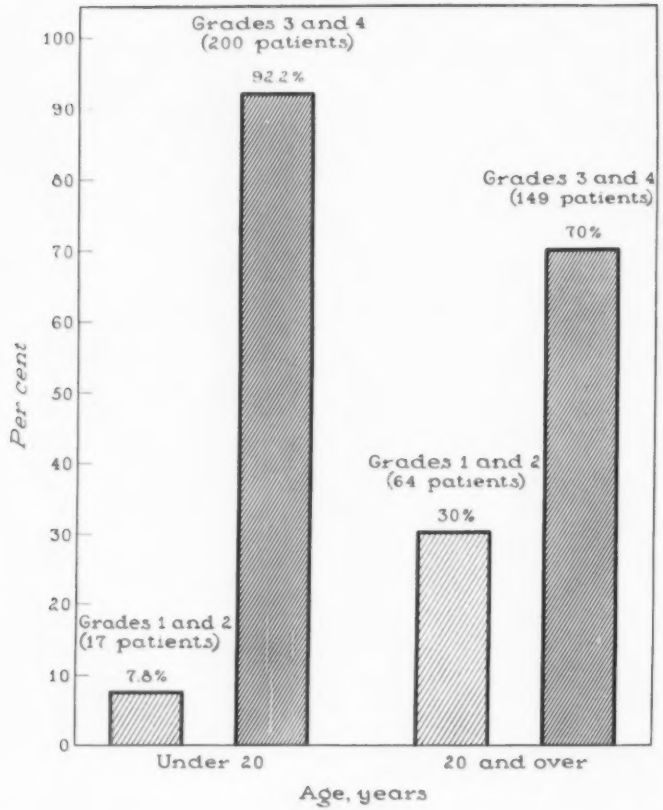

CHART V

Relationship between age of patient and grade of malignancy.

RELATIONSHIP TO PAGET'S DISEASE

Since there were only eight instances of osteogenic sarcoma complicating Paget's disease of bone in this series, no secondary peak incidence occurred in the older group of patients. Also, no such secondary peak was observed in the series of 160 osteogenic sarcomata reported from Memorial Hospital [5]. It seems possible that the tendency to report the complicated cases (that is, the development of osteogenic sarcoma in Paget's disease) introduces a selection factor that would affect smaller series reported and give an apparently higher incidence of osteogenic sarcoma in the latter decades, so often referred to.

SURVIVAL

Over-all Survival Rates

We have used the generally accepted five-year and ten-year survival periods, the length of survival being computed from the date of the institution of definitive therapy. The over-all figures are based on all patients regardless of the form of therapy employed, the location of the tumor, or the extent of the tumor. The five-year survival rate was based on 353 patients traced, the inquiry being made as of January 1, 1956. The five-year group included those patients treated in 1950 or earlier; the ten-year group consisted of 294 patients traced who had been treated in 1945 or earlier. As shown in Chart VI, 19.3 per cent survived five years and 15.3 per cent survived ten years.

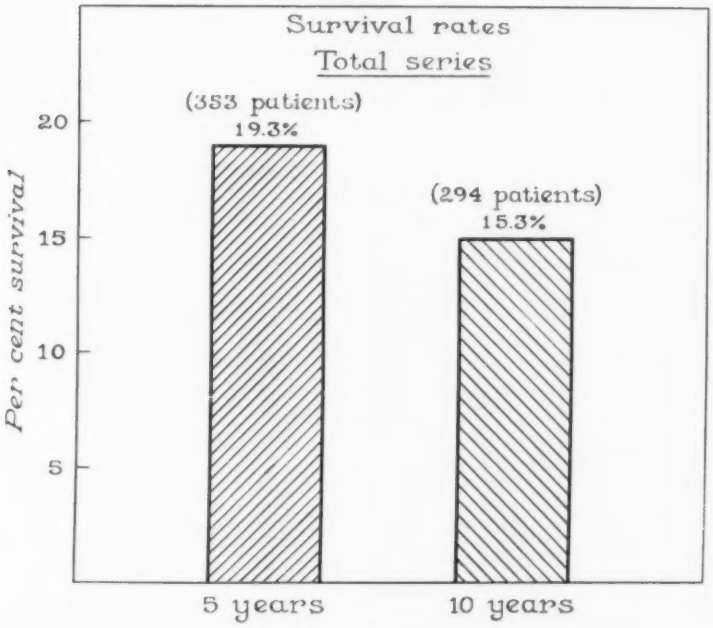

CHART VI

The majority of all patients had amputations. In fact, all but seven of the sixty-eight patients who survived five years or more had amputation as the definitive form of therapy. Local excision was performed in many patients, especially for tumors of the ribs or pelvis, and biopsy alone was performed in some.

Radiation therapy, when given, was used in conjunction with surgical measures or alone. It was the definitive form of therapy for about one-fifth of the tumors, a group composed chiefly of lesions not amenable to surgical ablation. Two patients with osteogenic sarcoma (both of the osteoblastic type), one with involvement of the upper part of the humerus and the other with involvement of a rib, have lived thirty-two years and nineteen years, respectively, after biopsy and radiation treatment.

Excision of the tumor (grossly complete), followed by radiation, resulted in five-year survival in five patients. The sarcoma was in the clavicle, fibula, and tibia in one patient each and in the femur in two. The patient with the tibial lesion died of heart trouble twenty-nine years after therapy. The patients with clavicular and fibular lesions succumbed to the effects of local recurrence and metastasis in the fifth and sixth years, respectively. One patient with involvement of the femur had local resection for a grade 1 osteogenic sarcoma at the lower end of the femur, received x-ray treatment, and, twelve years later, had an amputation for a grade 3 tumor in the same location. She is alive and well at present. The other patient with involvement of the femur had resection for a grade 2 osteogenic sarcoma in an osteochondroma; he is alive twenty-five years later. Most of the 4 percent of patients who died between five and ten years after diagnosis succumbed to the effects of the tumor. Many had highly anaplastic lesions; we cannot explain why metastatic deposits become manifest so long after removal of the primary sarcoma.

Survival According to Location of Tumor

Some of the osteogenic sarcomata were obviously in locations that precluded satisfactory surgical therapy. Prognosis is much more favorable when the tumor is amenable

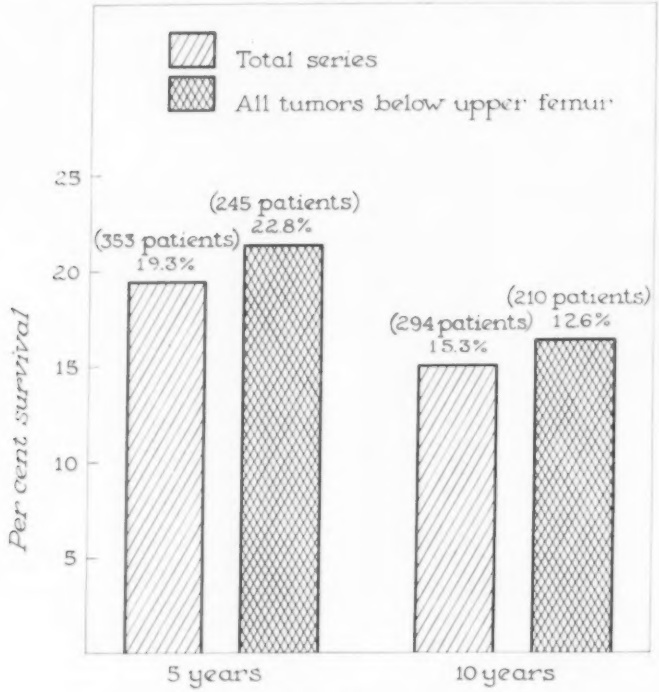

CHART VII

Survival rates for the series as a whole compared with rates for patients whose tumors were situated below the upper third of the femur.

to radical surgical treatment than when it is not, as when a flat bone is involved. For example, of thirty patients traced who had osteogenic sarcoma of the innominate bones, none survived five years. In order to obtain a better idea of how much the over-all survival rates were influenced by inclusion of the lesions that were not readily amenable to surgical treatment, we computed separately the survival figures for all tumors located below the upper end of the femur. This selection was also made because 69.4 per cent of the tumors in the group of patients traced occurred below this level; they comprise a statistically significant number. For these more readily treatable lesions the five-year and ten-year survival rates were 22.8 and 17.6 per cent, respectively (as compared with 19.3 per cent and 15.3 per cent for the entire group of osteogenic sarcomata) (Chart VII). Also, for comparison, 19.5 per cent of the thirty-two patients traced with osteogenic sarcoma of the upper extremity, including the upper end of the humerus, survived five years.

If one compares the survival rates for patients who had sarcoma of the tibia with the rates for those who had sarcoma of the middle and lower parts of the femur, a striking contrast is noted (Chart VIII). Thus, the five-year survival rate was 34.6 per cent for the patients with a tibial tumor but only 17 per cent for those with a femoral tumor. The reason for this difference is not clear. Although the incidence of low-grade lesions and of tumors of chondroblastic type was greater in the tibia, the prognosis was better for any variety of sarcoma that occurred in this bone. Perhaps the more exposed position of the tibia made for earlier diagnosis and treatment. Blood supply also may have been a factor.

Further breakdown of the survival data according to the long bone or the portion of long bone involved is not practical because the number of cases is not large enough to provide a statistically significant result. Because of the commonly held view that osteo-

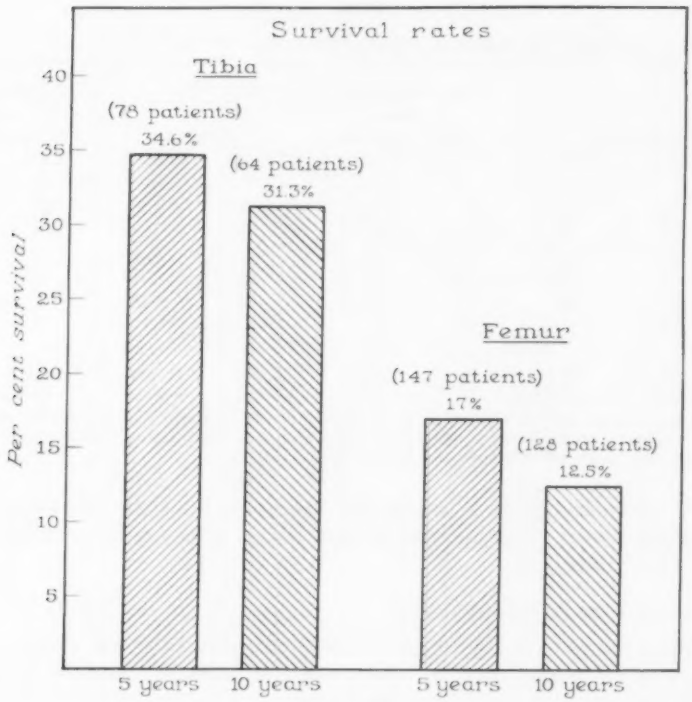

CHART VIII

genic sarcoma of the hands and feet has a good prognosis, it is interesting to note the extreme rarity with which these structures are involved and the fact that only two of the six patients eligible for five-year follow-up had been cured of such lesions.

Survival According to Histological Type of Osteogenic Sarcoma

Survival rates varied with the histological type of tumor. As noted in Chart IX, the patients with fibroblastic tumor had the most favorable over-all five-year survival rate (22.9 per cent). Those with chondroblastic tumor had a survival rate of 22.7 per cent; and those with osteoblastic tumor, comprising the largest number of the patients traced, had the poorest survival rate (15.6 per cent). Because of the relatively greater tendency for chondroblastic osteogenic sarcoma to involve the pelvic girdle, the difference in prognosis is even greater when one considers only the tumors occurring below the upper part of the femur. Thus, 35.2 per cent of the patients with chondroblastic osteogenic sarcoma, 28.8 per cent of those with fibroblastic sarcoma and 15.8 per cent of those with osteoblastic sarcoma below the upper part of the femur survived five years.

Survival According to Grade of Osteogenic Sarcoma

With patients with parosteal sarcoma being excluded, as mentioned previously, the combined five-year survival rate for patients with grade 1 and grade 2 tumors was 25.4 per cent (based on sixty-three patients traced). The combined five-year survival rate for patients with grade 3 and 4 tumors was 17.6 per cent (based on 290 patients traced) (Chart X). We grouped grade 1 and grade 2 tumors because there were very few grade 1 tumors, and we combined grade 3 and grade 4 tumors because of the very similar survival rates associated with them. Of the 353 patients traced for five years, six had grade 1

TABLE I

OSTEOGENIC SARCOMA: FIVE- AND TEN-YEAR SURVIVAL RATES BY AGE

Age (*Years*)	Patients (*Total*)	Patients (*Traced*)	Lived Five Years or More After Diagnosis (*No.*)	Lived Five Years or More After Diagnosis (*Per Cent* *)	Patients (*Total*)	Patients (*Traced*)	Lived Ten Years or More After Diagnosis (*No.*)	Lived Ten Years or More After Diagnosis (*Per Cent* *)
< 20	172	168	31	18.5	146	141	23	16.3
20–29	88	87	23	26.4	79	79	16	20.3
30–39	37	36	6	16.7	32	31	4	12.9
40–49	28	27	5	18.5	22	21	1	4.8
50–59	21	20	3	15.0	16	15	1	6.7
> 60	15	15	0		7	7	0	
Total	361	353	68	19.3	302	294	45	15.3

* Based on patients traced. Inquiry as of January 1, 1956. Included in the five-year group are only those patients operated on five years or more prior to the time of inquiry, that is, 1950 or earlier; the ten-year group includes only those patients operated on in 1945 or earlier.

lesions, fifty-seven had grade 2 lesions, 197 had grade 3 lesions, and ninety-three had grade 4 lesions. Specific survival rates for grades 1, 2, 3, and 4, respectively, were 16.7, 26.3, 17.8, and 17.2 per cent.

Survival According to Age of the Patient

In Table I are given the five- and ten-year survival rates by age groups. There is an indication that younger patients do better than older ones. The analysis is clearer if the series is divided into two age groups. For patients less than thirty years of age the five-

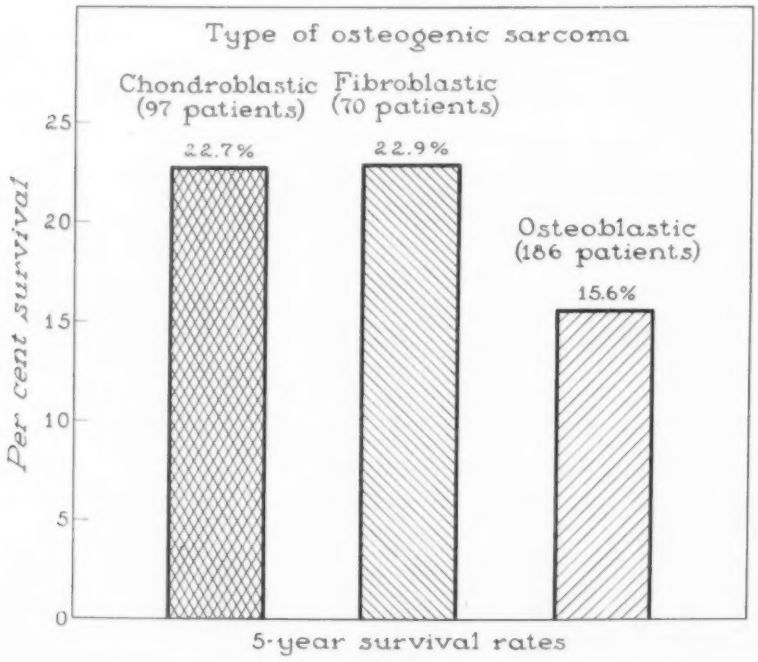

CHART IX

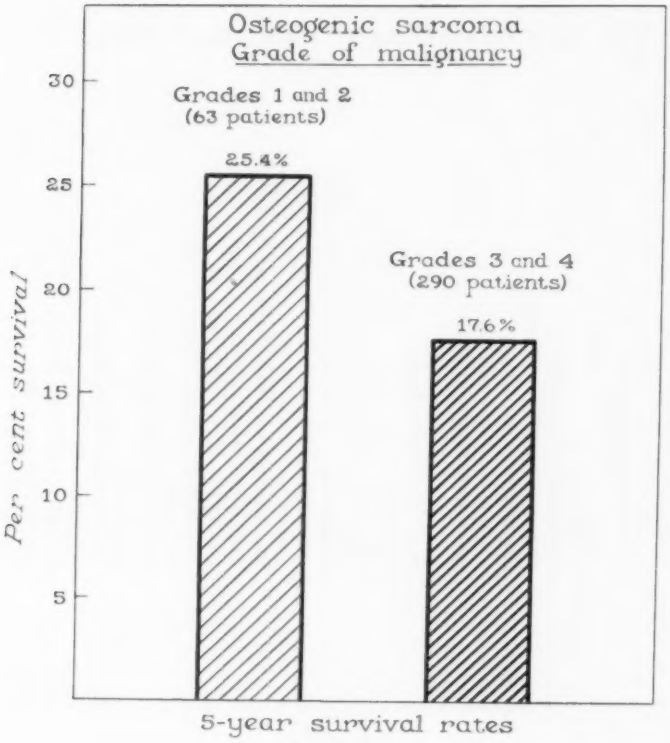

CHART X

year survival rate is 21.2 per cent as compared with 14.3 per cent for those patients thirty years old and older. The corresponding ten-year survival rates are 17.7 per cent and 8.1 per cent.

So that the reader may study the data on each patient surviving five years or longer, these data are given in Table II. The age, sex, location of tumor, preoperative duration of symptoms, grade of tumor, and treatment are given, as well as survival in years as of January 1, 1956.

DIFFERENTIAL DIAGNOSIS

Since chondrosarcomata and unmixed fibrosarcomata were excluded from this series, there remains no other primary malignant lesion of bone that is likely to be confused with osteogenic sarcoma. A few benign conditions require differentiation from it, however. Of these, heterotopic ossification, especially the florid phase of myositis ossificans, may be very troublesome when only the histological appearance is considered. The extra-osseous location of the tumor should make one suspect the correct diagnosis. Additional evidence is the production of orderly and directional osseous trabeculae and lack of true anaplasia in the actively proliferating cells (Fig. 5). Stereoroentgenographic evidence that the cortex of the adjacent bone is not involved points to myositis ossificans. As in the differential diagnosis of all bone tumors, a careful history should be taken. Significant injury will often have occurred just prior to the onset of the tumor[7].

Fibrous dysplasia and giant osteoid osteoma (non-osteogenic fibroma) of bone may exhibit mitotic figures, but the proliferating cells lack the anaplasia required for the diagnosis of osteogenic sarcoma.

TABLE II

LONG-TERM SURVIVORS

Age	Sex	Location of Tumor	Preoperative Duration of Symptoms (*Months*)	Grade	Treatment	Survival (*Years*)
			Osteoblastic Osteogenic Sarcoma (29 Patients)			
14	M	Upper femur	3	4	Hindquarter amputation	10
30	M	Mid-femur	24	3	Roentgen therapy, disarticulation	12 †
23	F	Mid-femur	6	3	Disarticulation	13
16	M	Mid-femur	1½	3	Amputation	11
23	M	Lower femur	5	3	Amputation, roentgen therapy	20 ††
30	F	Lower femur	4	2	Amputation	29
20	M	Lower femur	18	2	Local excision, twice	25
11	M	Lower femur	2	3	Amputation	11
28	F	Lower femur	6	4	Amputation	11
21	F	Lower femur	¾	4	Amputation	8
43	F	Lower femur	9	2	Amputation	5
21	M	Upper tibia	3	4	Amputation, roentgen therapy	21
24	F	Upper tibia	4	4	Amputation	20
11	F	Upper tibia	2	3	Local excision, amputation, roentgen therapy	9 †
16	M	Upper tibia	4	3	Amputation, roentgen therapy	28
16	M	Upper tibia	1	4	Roentgen therapy, amputation	25
15	M	Upper tibia	4	4	Amputation, roentgen therapy, Coley's toxin	21
17	M	Upper tibia	5	3	Amputation	7
15	M	Upper tibia	6	3	Amputation, roentgen therapy	13
12	M	Upper tibia	2	4	Amputation	12
15	F	Lower tibia	8	3	Amputation, roentgen therapy	22
55	M	Upper fibula	5	4	Amputation	6 ††
17	M	Upper fibula	2	4	Amputation, roentgen therapy	5 ††
25	M	Upper humerus	24	3	Forequarter amputation	39
9	F	Upper humerus	5	3	Roentgen therapy	32
19	M	Upper radius	48	4	Local excision, amputation, roentgen therapy, Coley's toxin	8
34	M	Hand	48	2	Local excision, forearm amputation	17 ††
43	M	Hand	12	2	Local excision, twice; amputation	7 ††
52	M	Rib, sixth	7	4	Local excision, roentgen therapy	19

Chondroblastic Osteogenic Sarcoma (22 Patients)						
17	F	Mid-femur	3	2	Roentgen therapy, disarticulation	24
17	M	Mid-femur	1½	3	Disarticulation	8
25	M	Lower femur	7	3	Amputation	7
21	M	Lower femur	4	3	Amputation, roentgen therapy	24
14	M	Lower femur	2	3	Amputation	17
10	F	Lower femur	3	3	Amputation	9 ††
16	M	Lower femur	3	3	Amputation	11
14	M	Lower femur	1½	4	Amputation	6
12	M	Lower femur	½	3	Disarticulation	5
22	M	Upper tibia	4	3	Local excision, amputation, Coley's toxin	5 †
15	M	Upper tibia	18	3	Amputation, roentgen therapy	28
20	F	Upper tibia	9	2	Local excision	29 ††
20	M	Upper tibia	2	3	Amputation, roentgen therapy	7 ††
18	M	Upper tibia	5	3	Amputation	17
25	M	Upper tibia	9	2	Amputation	7 †
26	F	Upper tibia	12	2	Local excision, amputation	12
16	M	Mid-tibia	2	2	Amputation	43
21	M	Mid-tibia	18	2	Amputation	16
13	F	Lower tibia	9	2	Disarticulation at the knee	32
17	F	Upper humerus	5	2	Forequarter amputation	46
24	M	Upper ulna	30	3	Amputation	42
43	M	Clavicle	18	3	Local excision, roentgen therapy	5 †
Fibroblastic Osteogenic Sarcoma (16 Patients)						
38	M	Lower femur	8	4	Amputation, Coley's toxin	33
27	M	Lower femur	5	3	Amputation, roentgen therapy	34
9	M	Lower femur	3	3	Amputation, roentgen therapy, Coley's toxin	32
29	F	Lower femur	12	1	Local excision, roentgen therapy	29
				3	Amputation twelve years later	
22	M	Lower femur	9	3	Roentgen therapy, amputation	7
26	M	Lower femur	3	4	Amputation	5 †
29	M	Upper tibia	9	2	Amputation	26 ††
40	M	Upper tibia	6	3	Amputation, local excision, Coley's toxin	16 ††
19	M	Upper tibia	2	3	Roentgen therapy, amputation	30
27	F	Upper tibia	9	3	Roentgen therapy, amputation	22
33	F	Upper tibia	6	3	Amputation	10
15	M	Mid-tibia	9	4	Amputation	29
43	F	Upper fibula	2	2	Local excision	6 †
12	F	Upper humerus	3	3	Disarticulation	38
38	F	Upper tibia	8	3	Amputation	5
19	M	Upper fibula	3	3	Excision, amputation	28

† Died of sarcoma. †† Died of unknown or unrelated cause.

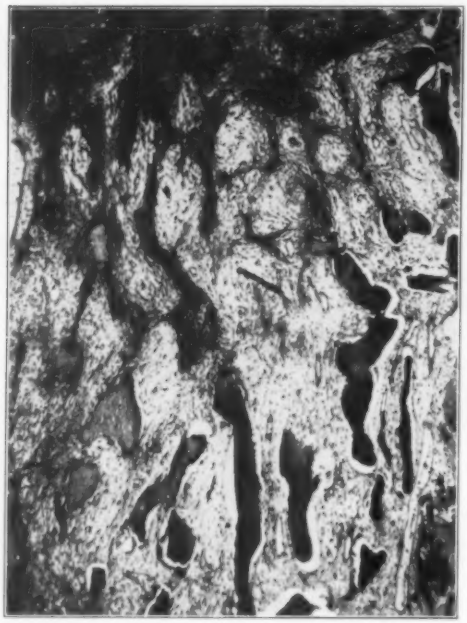

FIG. 5

FIG. 6

Fig. 5: Florid myositis ossificans with actively proliferating cells, above, shading into well formed osseous trabeculae (hematoxylin and eosin. × 43).

Fig. 6: Roentgen appearance of osteogenic sarcoma, upper part of femur, treated by hindquarter amputation. The patient was alive and well ten years later.

About one-fourth of osteogenic sarcomata contain multinucleated benign cells (benign giant cells), and many benign giant-cell tumors show foci of osteoid production. These facts make it possible to mistake an osteogenic sarcoma for a benign giant-cell tumor, sometimes with disastrous delay in radical therapy. Roentgenograms often aid in the differentiation, but again one must rely on the anaplasia of the sarcoma to supply the answer.

COMMENT

The fact that nearly 20 per cent of the patients with osteogenic sarcoma survive five years after definitive therapy is the most significant observation in our investigation. Standard texts such as those of Ackerman and Lichtenstein suggest that a five-year survival rate of 5 to 10 per cent is all that can be expected. Boyd states that "for the present . . . our knowledge is not sufficient to allow us to give a really reliable prognosis." The wisdom of his judgment is apparent when one recognizes that Lichtenstein's pessimistic figure is based on only "some 25 proved cases of osteogenic sarcoma, which showed only 2 survivors at 5 years or more". Data from small series of cases have little or no statistical significance; yet conclusions regarding therapy based on such meager evidence are recorded in the literature and fallacious information is perpetuated when the articles are used for reference.

Coley and Harrold provided an optimistic note in 1950, when they reported an analysis of fifty-nine cases of osteogenic sarcoma with survival of the patient for five years or more. Although they included chondrosarcomata and spindle-cell sarcomata in their series of osteogenic sarcomata, we endorse their final statement, "It is hoped . . . to dispel the attitude, which seems all too prevalent, that this disease is uniformly fatal and that therapy is of so little value as to call for no great effort to reach an early diagnosis and to institute prompt appropriate treatment." Our large group of patients with osteoblastic sarcoma, although they represent the worst type, had an over-all five-year survival rate of 15.6 per cent.

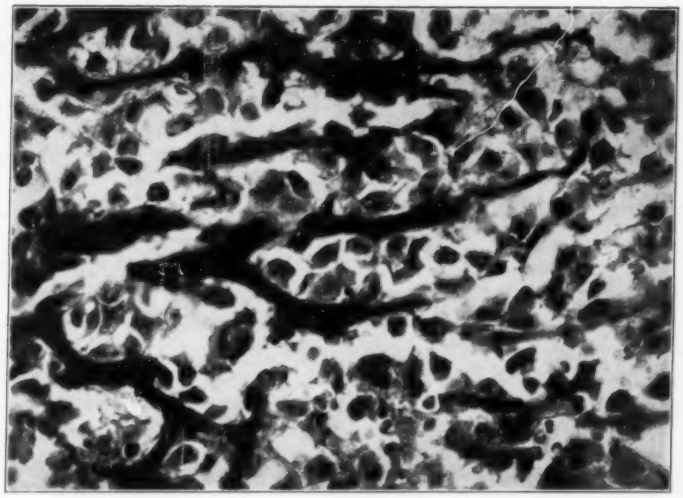

FIG. 7

Osteoblastic sarcoma illustrated in Fig. 6 (hematoxylin and eosin, × 470).

The treatment that has been most successful in our hands is early surgical ablation. There obviously must be a time when lethal embolization (metastasis) from a malignant tumor occurs; successful surgical therapy must precede this time. Our general policy has been to amputate the affected extremity as soon as possible after the correct diagnosis has been established. Ordinarily in suspected osteogenic sarcoma of the extremities, two tourniquets are applied, one above the tumor and one above the proposed site of amputation. After the diagnosis has been established by examination of fresh frozen sections of biopsy material, amputation is performed between the tourniquets. This precludes the possible dissemination of tumor emboli by the biopsy procedure. Practically all osteogenic sarcomata have soft parts from which a diagnosis can readily be made by the fresh-frozen-section technique. Many pathologists are reluctant to make a final diagnosis of bone tumor on the basis of fresh frozen sections. The non-calcified or only slightly calcified portions that almost all bone tumors contain require little or no decalcification and allow one to obtain permanent sections for study within one day. Such soft zones, moreover, contain the most easily identified portions of malignant tumors of bone. Detailed study of heavily calcified portions of these tumors or of the surrounding bone is unnecessary for the determination of correct therapy.

What is the proper level of amputation? The general principle of amputating through the bone above the one affected by tumor seems wise, but this requires modification in the treatment of the common sarcomata of the distal part of the femur. In most of the patients in our series, amputation was performed through the upper part of the femur. In recent years, disarticulation at the hip has been done in some, but the number of cases is insufficient to allow a valid comparison of the two levels of amputation. In amputation through the affected bone, the level of transection must be examined for evidence of involvement of the marrow by the tumor. We have two patients who have survived five years because such spread was detected and more bone was removed. One patient with osteogenic sarcoma of the upper end of the femur (Figs. 6 and 7) and two with such tumors of the upper end of the humerus have been cured by hindquarter and forequarter amputations, respectively.

Cade recently advocated primary irradiation therapy for osteogenic sarcoma. His plan is based on the assumption that the local tumor can be controlled by irradiation so

that metastasis will not occur. He has speculated that metastatic lesions that have developed prior to irradiation will become manifest during the period of treatment and observation, so that unnecessary amputation can be avoided. He stated that, "The very poor and disappointing results of amputation dictate an urgent policy of trying some other form of treatment." It will be interesting to see later results of his investigation.

The rate of growth and the time of metastasis are quite variable in patients with osteogenic sarcoma. Individual resistance to tumor, based on many postulated factors including hormonal, is still an unknown in oncology.

SUMMARY AND CONCLUSIONS

Four hundred and thirty patients who had pathologically verified osteogenic sarcoma and who were treated at the Mayo Clinic from 1909 through December 1955, form the basis of this report. Patients with juxtacortical or parosteal sarcoma and osteogenic sarcoma of the jaw were not included in the series. Data on location of the tumor, age and sex of the patient, tumor type, grade of malignancy, and survival are given. Ninety-seven per cent of the patients were traced and adequate follow-up data were obtained.

Osteogenic sarcoma is defined as a malignant lesion of bone, the proliferating neoplastic cells of which produce osteoid. It is the most commonly encountered malignant primary tumor of bone, exclusive of multiple myeloma. It may be classified microscopically as osteoblastic, chondroblastic, or fibroblastic. It must be especially differentiated from chondrosarcoma, fibrosarcoma, heterotopic ossification (myositis ossificans), fibrous dysplasia, non-osteogenic fibroma, and giant-cell tumor.

Treatment in this series usually consisted in amputation. Local resection was performed in some cases and biopsy alone in some; radiation therapy was frequently used in conjunction with these surgical procedures.

Of the entire group of patients with osteogenic sarcoma, 19.3 per cent survived five years and 15.3 per cent survived ten years from the date of definitive treatment. The corresponding rates for patients with lesions readily amenable to amputation (below the upper third of the femur) were 22.8 per cent and 17.6 per cent, respectively.

The five-year survival rate for patients with lesions of the tibia was 34.6 per cent, while the rate for patients with lesions of the middle and lower thirds of the femur was only 17 per cent.

Patients who had osteoblastic osteogenic sarcoma had the poorest five-year survival rate (15.6 per cent) when compared with those who had chondroblastic or fibroblastic sarcoma.

There was a definite relationship between grade of tumor (Broders' method) and survival, the five-year survival rate being 25.4 per cent for patients with grade 1 and grade 2 tumors and 17.6 per cent for those with grade 3 and grade 4 tumors.

The five-year survival rate of nearly 20 per cent obtained for the entire series of patients with osteogenic sarcoma seems to be extremely significant, especially when it is compared with other published data showing lower survival rates. Our figures have statistical importance because of the large number of patients traced.

The treatment of osteogenic sarcoma that has been most successful in our hands is early surgical ablation. We see no theoretical or proved reason at present for any other form of therapy, unless amputation is not possible.

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DISCUSSION

Dr. J. Vernon Luck, Los Angeles, California: My personal experience and that of my associates in this field has been small in comparison with that of Dr. Coventry and Dr. Dahlin. This makes me uncomfortable in presenting my views, but present them I must, if I am to fulfill this assignment. One member of our group (Louis Lichtenstein) has been reprimanded by the authors for drawing conclusions on the basis of a small experience, as reflected by a paper on this subject. He and I both are among those guilty of what the authors refer to as undue pessimism. Our results, as we have observed them, have given us little reason for optimism, particularly in the instance of osteoblastic sarcoma. This is truly a catastrophic tumor. Classification of bone tumors continues to be confused, and this will no doubt continue as long as we base our conclusions on factors other than etiology. With virtually no knowledge of the etiology, we must be content with a less sound basis from which to draw conclusions. The predominant cell—or tissue—has been the favored basis. Dr. Coventry and Dr. Dahlin have been inclined to depart somewhat from this basis and use the creation of widespread, even small, foci of osteoid as a basis for classifying the osteogenic sarcomata.

We have had the opportunity of making a study of many histological sections of entire tumors of the osteogenic series. There are very few in which at least scattered foci of osteoid cannot be found, even in the chondrosarcomata and fibrosarcomata. It has been our custom to disregard these foci and to consider the greatest part of the tumor as the better basis for classification. We have had the feeling that scattered foci of osteoid may be primarily a reaction to local environmental factors; if so, the presence of osteoid would serve as an inadequate basis for classification.

Occasionally, an osteogenic sarcoma is so anaplastic and undifferentiated that it is not until the pulmonary metastases are studied histologically that a definite diagnosis can be made.

The degree of cellular anaplasia graded by Broders' method (1 to 4) has not in our hands been a reliable method of grading these tumors. The degree of anaplasia has varied widely from one area of the tumor to the other. The highest degree of anaplasia occurs frequently at the periphery. It is well to do widespread histological sampling through the tumor mass in order to arrive at an understanding and appreciation of the most ominous aspects of the tumor.

The authors separate the parosteal osteogenic sarcomata from others of the group; this seems to us entirely valid on both a clinical and histological basis. The authors had a five-year survival rate of 34.6 per cent of patients with osteogenic sarcoma of the tibia and of 17 per cent of patients with osteogenic sarcoma of the femur. These are remarkably high survival rates. In the osteoblastic type of osteogenic sarcoma, 15.6 per cent was the survival rate. This latter statistic is considerably higher than is ours—10 per cent or slightly less. It is well known that in patients with chondrogenic and osteogenic sarcomata there is a higher survival rate. If some tumors of the chondrogenic and fibrogenic group are included in the osteoblastic classification, it would naturally increase the survival rate.

In regard to treatment, we are not so pessimistic as Cade, McWhirter, and other roentgenologists who take such a pessimistic view that no surgery is recommended—only roentgen therapy. We do not agree with this but agree with the authors that early amputation is the treatment of choice, when feasible. We, in Los Angeles, favor disarticulation of the hip when involvement of the lower half of the femur exists, whereas another group recommends high amputation. It would be ideal if a frozen section were reliable enough to be used regularly. We do not agree with the authors that it is often a reliable method. It has been our practice to study the predominant sections with great care before arriving at a final diagnosis and prescription for management. Very few pathologists wish to have amputation carried out on the basis of their interpretation of frozen sections.

Dr. C. Howard Hatcher, Chicago, Illinois: Much of our present-day knowledge of bone sarcoma as well as some confusion has come from the early studies done on collections of material such as in the Bone Sarcoma Registry of the American College of Surgeons. It was inevitable that some erroneous statistics and conclusions would derive from material collected from wide sources and varying so much in the perfection of its preparation. In consideration of the lack of knowledge of bone pathology at the time of these earlier studies, it is not surprising that misinterpretations were made.

Dr. Coventry and Dr. Dahlin have reported on their study of a large number of patients who had bone-forming sarcomata. An earlier report by Dr. Dahlin and Dr. Henderson was concerned with cartilage-forming tumors. They are interested in grouping or classifying tumors according to the character of the tissue produced. They reject the classification of tumors which implies knowledge of the exact site of origin, such as periosteal sarcoma, or which characterizes secondary manifestations such as sclerosing, osteolytic, or telangiectatic sarcoma. With this I agree. Indeed I would also do away with the term *osteogenic sarcoma* since it is variously used to indicate either a tumor of bone-forming cells or any tumor arising within bone. The term *osteosarcoma*, applied almost one century ago by Virchow, seems preferable for indicating a bone-forming sarcoma.

The authors' further division of the bone-forming sarcomata into fibroblastic and chondroblastic types is to me confusing. It is true that some tumors form but little neoplastic bone while others do so abundantly. Also some which are rapidly growing or are composed of very immature osteoblasts may form some cartilage. Nevertheless, they seem to belong in the group of osteosarcomata and they vary only in the degree with which they produce neoplastic bone. Broadly speaking one can classify most tumors as osteosarcoma, chondrosarcoma, or fibrosarcoma; but there is no sharp demarcation of one group from another, just as there is not always sharp distinction between benignity and malignancy.

The tumor which the authors term *chondroblastic osteogenic sarcoma* I have considered as an osteosarcoma which forms very immature skeletal tissue. Our experience with this neoplasm has led us to the conclusion that it is the most highly malignant of bone sarcomata. In our files at the University of Chicago we find not a single patient who has survived such a neoplasm. Also, in contrast to the experience of the authors, of the patients who have had long survival following eradication of osteosarcoma, the majority of them had such a densely ossifying neoplasm that the secondary product of the tumor cells seemed to choke out the malignant cells.

The over-all survival statistics which the authors present seem very favorable. In our smaller group of patients the survival rate from osteosarcoma is about 5 per cent. I say *about* because each time I review the group uncertainty arises as to the exact classification of some of the tumors, so that the statistical analysis is altered. I am sure the authors' statistics are correct, but variations do come from individual interpretations as to just what tumors should be placed within a given group.

As to treatment, I believe all will agree that surgical ablation of the tumor is to be preferred to irradiation. I question if there is any advantage of hip disarticulation over mid-thigh amputation for most tumors of the distal end of the femur. If removal of the primary neoplasm is accomplished, the fate of the patient depends upon the behavior of the tumor cells prior to surgical removal of the lesion.

Dr. Dahlin (concluding): The division of osteogenic sarcomata into three major types depending on whether osteoid, fibromatoid, or chondroid production dominates the histological picture has two main purposes. It emphasizes the wide variation in microscopic pattern in tumors with similar skeletal localization, age distribution, and marked tendency for early hematogenous metastasis. The recognition of osteoid production by malignant-tumor cells allows differentiation of osteogenic sarcomata from unmixed chondrosarcomata, which have a much slower clinical evolution and occur in a distinctly older average age group. Separating unmixed fibrosarcomata from fibroblastic osteogenic sarcomata, on the other hand, has little more than questionable didactic value because both develop rapidly and tend to metastasize early.

The suggestion that the selection of cases accounts for our relatively good survival figures does not weather critical analysis. Our osteoblastic group, in which no one could doubt the designation of osteogenic sarcoma, had a survival rate not markedly different (15 per cent) from the over-all survival rate (19 per cent). Furthermore, our unmixed chondrosarcomata, except in recent years when therapy has been more radical, have been at least as lethal in the long run as osteogenic sarcomata. Including unmixed fibrosarcomata of bone would not appreciably alter the survival data.

Grading of osteogenic sarcomata by the method of Broders is difficult and apparently has little practical value. The parosteal variant, however, is characteristically low grade.

Dr. Luck has correctly stated that osteoid may be difficult to identify. We have adopted the policy that when the homogeneous, pink-staining substance in a section was not distinguishable from osteoid, we have considered it to be osteoid.

The Transfixion Hip Prosthesis

Observations Based upon Five Years of Use

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INTRODUCTION

The hopeful enthusiasm that greeted the original report of the Judet brothers has given way to widespread discouragement. Accounting for this have been a wide variety of surgical complications, prosthetic failures due to wear and tear and breakage, prosthetic instability, disappointing ultimate gains in range of motion and power, pain, and limp. Results of this sort have obscured the brilliant, if sporadic, salvage that the procedure has yielded, results that indicate how much the use of a femoral-head prosthesis can offer if its defects can be analyzed and corrected.

Some of the reported complications have been of a general surgical nature and some have clearly been due to faulty insertion technique. A high proportion, however, have been directly or indirectly caused by inadequacies of the prosthesis—faults that would inevitably occur in the development of a new appliance designed to withstand a heavy and sustained burden. Once in place, the prosthesis offers no ready access for repair or adjustment, and its durability must be of high quality. Although fixation of the prosthesis to the host femur must remain an unnatural marriage of bone to metal in which true healing can never be achieved, its stability must be sufficient to overcome the severe strains and jolts of daily living, perhaps for decades. Failure of stability causes not only gradual prosthetic migration but also diminished mechanical efficiency. Especially insidious are the manifestations of small degrees of sustained laxity which provoke hyperaemia and inflammatory bone resorption accompanied by pain and limp.

If the principle of the use of a femoral-head prosthesis is to receive fair evaluation, effort must be made to construct an instrument capable of overcoming the drawbacks that have resulted in so many disastrous consequences.

The present study, initiated over five years ago, has been directed to improving durability, stability, and adaptability in the belief that gains achieved in these respects would be reflected not only mechanically but also in improved clinical function. The separate study of the mechanical and physiological factors concerned in each of these requirements suggested certain practical measures which might materially improve the value of the device. A summary of these basic considerations and their practical application in prosthetic design constitute the first part of this report. The device itself and the method of insertion are then to be described. Technical and clinical results in all patients who were operated upon from two to five years ago will be reviewed.

BASIC CONSIDERATIONS UNDERLYING DESIGN

1. *Durability*

The stresses and strains borne by a functioning prosthesis call for the highest measure of resistance to wear and tear, to breakage, and to the late occurrence of fatigue fracture. The failures caused by wear and tear and breakage of plastic prostheses clearly indicate that a metal prosthesis is preferable. No apparent disadvantage of metal could outweigh its greater resistance to wear and tear.

Resistance to breakage, especially of the shaft and at the vulnerable trochanteric angle, is determined by the strength of the device itself and by the distribution and

strength of its bone support. Obviously, the strength of the device itself may be augmented by increased bulk. Beyond certain limits, however, a larger prosthesis encroaches upon the bone of the host femur and weakens this structure. Increased strength of metallic devices may be more effectively and less destructively provided by bracing—the method elected for the construction of the prosthesis to be presented. Bracing, as employed in a lamp post, crane, or derrick, was suggested in order to reinforce the critical trochanteric angle.

The importance of the surrounding supportive bone in resisting breakage of the prosthesis calls for its careful protection during the insertion. In the insertion, it seemed advisable to avoid the use of irregularly curved shafts which destroy more bone than these shafts ultimately displace. For accuracy in the preparation of the bone bed, the use of straight elements no smaller above than below seemed advisable. Since the insertion of a single-piece braced prosthesis could not be accomplished without excessive destruction of surrounding bone, a prosthesis that permits the separate insertion of each segment was decided upon, the parts to be articulated during the operation. It was believed that the theoretical objections to a multiple-part prosthesis could be overcome by careful design—preservation of supportive bone is of greater importance. The risk of fatigue fracture, present in all metals subjected to constant repeated bending strain, must be resisted by maintainance of safeguards while the prosthesis is *in situ*. This problem is intimately bound to that of stability.

2. *Stability*

A prosthesis may be loose directly after insertion or may become so at any subsequent time as a result of electrochemical action, excessive and sudden mechanical impact, atrophy of surrounding bone caused by excessive pressure or lack of function, or of any combination of these. Whether the laxity is initially present or develops later, it tends to increase with variable speed and with progressive clinical deterioration. Moreover, the lack of bone support subjects the prosthesis to increased bending stress and increased risk of late fatigue fracture.

Initial laxity may be combatted by the general design principles already described under "Durability" and, as has been demonstrated in the fixation of long-bone fractures, by transfixion.

The laxity that develops later is rarely due to electrochemical action as has been shown by experience with inert internal-fixation devices. When fracture healing removes the stress and strain upon internal-fixation screws, they generally remain firm and are painless indefinitely. If the fracture fails to heal, however, persistent stresses will inevitably cause the screws to loosen and to wander or to fracture and become painful. From these experiences, the mechanical factor would appear to be the more important.

Unlike the temporary function of internal-fixation devices, the weight-bearing prosthesis is subjected to lasting stresses and strains which persist as long as the prosthesis functions. Although the stresses cannot be avoided, means are available by which their effects may be neutralized. The first means of neutralizing their effects is the use of the widest contact of surface bone to metal practicable. The broader the contact area, the less is the pressure per unit area. Wide resolution and dispersion of weight-bearing stresses lessen the direct force of the metal on the bone surfaces. This may be accomplished by utilizing a transfixion shaft as a support that will accept a share of the direct force and disperse it in several directions by torque. The wide dispersion of lateral forces by a transfixion shaft should prove particularly effective in resisting the common weakness of fixation devices.

Perhaps the most important means by which the prosthesis may be shielded from excessive stress consists in the allocation of a large share of weight-bearing directly upon the stump of the femoral neck, from which area it is distributed to the femur in the

normal manner. The device must be regarded as experimental since it is believed by many that the neck stump is untrustworthy and is prone to gradual disintegration and absorption. Certain designers of prostheses, accepting this point of view, have required total amputation of the remaining portions of the femoral neck for the insertion of their instruments.

There is certainly ample evidence to show that the femoral stump may disappear when the neck is not utilized for weight-bearing (as in unhealed fractures of the femoral neck) or when it is subject to abrasion (when there is a lax and rotating prosthesis). Such is not the case, however, when a well immobilized fracture of the femoral neck heals. Whether the femoral stump can be counted on to remain and to hypertrophy in the absence of abrasion and under metallic weight-bearing has not been definitely established. In the device to be described, it is believed that by completely stabilizing and preventing motion in the part that is superimposed upon the neck stump, the intra-osseous portion of the instrument could be relieved of the greater part of the weight-bearing stress. The probability of success if the stump proved trustworthy under these conditions led to the experimental incorporation of elements in the design which would take advantage of the facts. The outcome of this experiment will be considered in the follow-up studies included in this report. On a purely empirical basis, it seemed that if the prosthetic head were to lock in the acetabular socket, a metal-to-metal articulation distal to it might maintain motion and at the same time protect the bone-to-metal bond from severe impacts of the limits of motion. Accordingly, a pivoting head, rotating freely on a metallic pin and base, seemed advantageous.

Because of the lasting vulnerability of any bone-to-metal fixation, the risk of traumatic displacement of the prosthesis will always be present. If such displacement of the prosthesis is angular, it could severely compromise subsequent weight-bearing. Moderate displacement, consisting in downward shift only, would still provide a firm, stable, and useful hip joint. The instrument, therefore, should be designed in such a way that downward shift rather than rotatory or angular displacement would occur in the event of bone erosion.

3. *Adaptability*

There are at least two reasons for the demand that the hip prosthesis possess at least some degree of adaptability.

1. The variable length of the femoral neck available in candidates for the insertion of a femoral-head prosthesis requires adaptability if the full benefit of available neck is to be obtained. The prosthesis should be capable of utilizing available neck and should not necessitate much amputation. The prosthesis should also be capable of firm seating when the remaining portion of the femoral neck is minimal.

2. Of equal importance is the ability of the prosthesis to restore an approximately normal head-to-trochanter interval even when the neck remaining is short. This is important in the prevention of the tendency of the prosthetic head to subluxate and in the avoidance of a Trendelenburg limp. A shortened femoral neck increases demands on the glutaeus medius and the tendency to Trendelenburg gait by two mechanisms: (a) direct shortening of the lever arm and (b) medial shift of the trochanter which carries with it the point of attachment of the muscle itself, causing it to pull obliquely and less efficiently. According to rough calculations based upon the method employed by Ponseti [1], these combined mechanisms can impose an extra burden of some twenty to forty pounds upon the involved muscles for each centimeter that the head-to-trochanter distance is shortened. The normal head-to-trochanter interval is important in resisting the forces responsible for the postoperative subluxation or dislocation which frequently occurs in other prosthetic reconstructions.

Provision for adaptability in the device to meet the requirements outlined in the

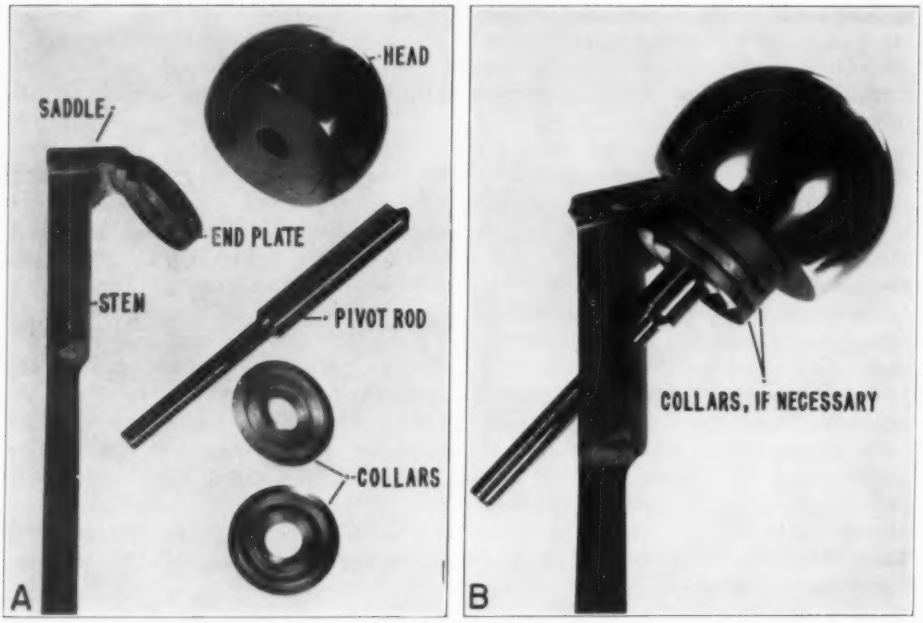

FIG. 1

Fig. 1: The transfixion prosthesis: *A*, dissembled; *B*, assembled. When necessary, accessory colors may be used under the end-plate to ensure direct bony support.

FIG. 2

Fig. 2: The transfixion prosthesis *in situ*.

foregoing is set forth in the following description of the device and of the procedure for its insertion.

4. *The Device*

The transfixion prosthesis described here combines the mechanical principle of the crane for strength and the transfixion principle for dispersion of weight-bearing pressure and for firm fixation. It is composed of three parts as illustrated in Figure 1, *A* and *B*. Originally, the stem and saddle were separate and were bolted together during the operation after the stem had been inserted into the femur. With the use of the Gibson approach, this separate assembly proved cumbersome and unnecessary; it was discarded.

The stem is squared above, triangular below, and pointed at the tip. Its squared section is cannulated to receive the pivot rod at the correct angle. The saddle is broadened transversely to rest upon the crest of the neck stump. The under surface of the

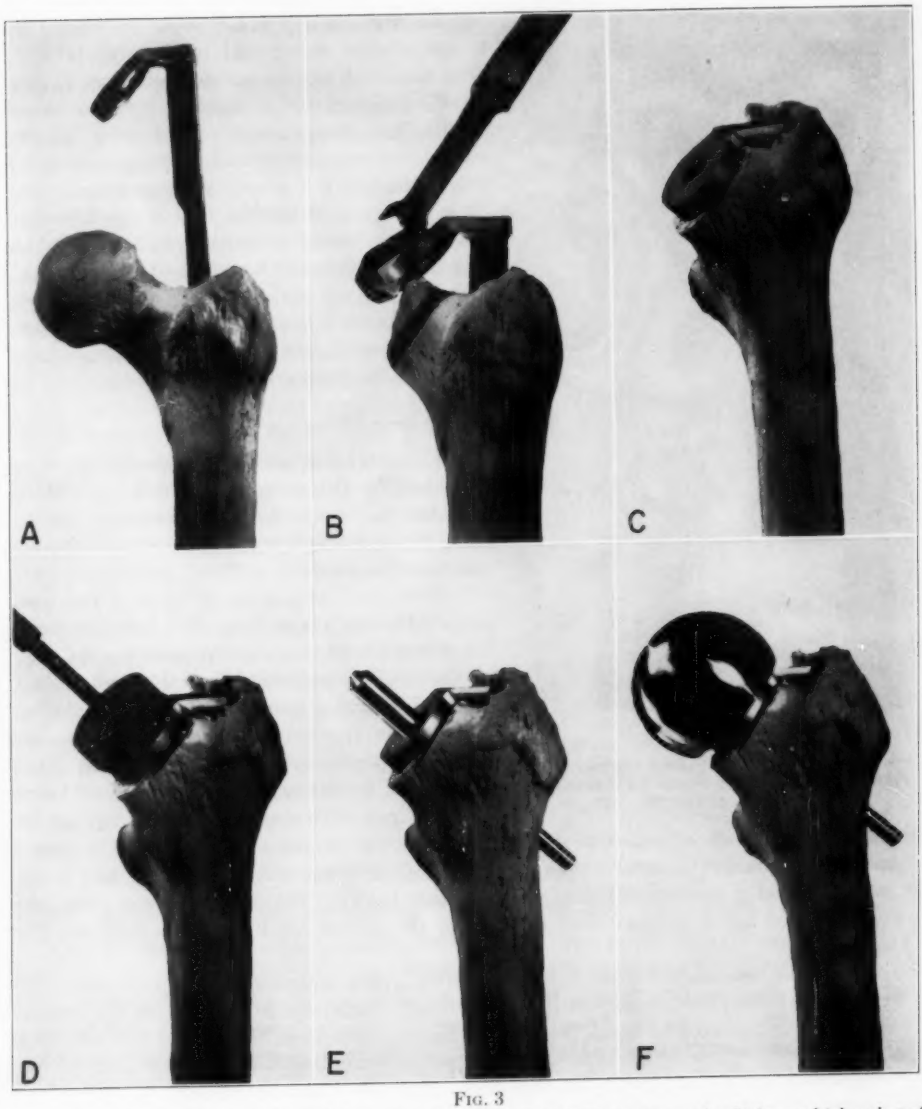

FIG. 3

Steps of the insertion procedure: *A*, insertion of stem; *B*, use of twister for precise fitting and trimming of stump; *C*, main rod is hammered home—note end-plate contact with stump of the femoral neck; *D*, use of drill guide to ensure accurate direction for transfixion of shaft; *E*, pivot rod tapped into position through above channel; and *F*, application of head of proper size.

cannulated end-plate is corrugated to provide greater surface area to rest against the cervical stump and, if necessary, to mesh with the underlying and reciprocally corrugated collars. The pivot rod, upon which the head rests, penetrates the end-plate, transfixes the stem until the shoulder formed by its larger proximal half abuts against the side of the stem, and then emerges through the outer femoral cortex (Fig. 2). When the remaining femoral neck is small, the corrugated collars may be used to restore length. They mesh with the corrugations of the under surface of the end-plate and with each other. The major portion of the body weight is applied to the neck stump. The remainder is shunted to the

FIG. 4

Accessory collars can be used in order to ensure end-plate contact if the stump is short.

central transfixion, where it is converted to torque and is distributed to the large surface area and leverage of the cross beams. Downward displacement is resisted by the broad saddle that rests on top of the neck, by the corrugated wide surface of the angle plate, by the support of the pivot rod, especially by the outer cortex, and by the firm wedge-like grip between the stem and the end-plate which is constantly reinforced by weight-bearing thrust. The integrity of the assembly is assured when the head piece is in the acetabulum. Areas subjected to special strain have been reinforced and tested before clinical use.

5. Insertion Procedure

The lateral approach to the hip joint as described by Gibson and modified by McFarland has proved excellent for exposure of the crest of the femoral neck and consequently for the insertion of the transfixion prosthesis.

With the stem rotated so that the end-plate will be in approximate alignment with the femoral neck, a chosen point upon the apex of the neck is penetrated by the pointed tip. The rod is driven down the femoral shaft (Fig. 3, *A*). As the saddle-plate approaches the stump, opportunity for precise fitting is given (Fig. 3, *B*). Rotatory deviation is corrected with a vise-grip or with a special twister. Any prominence above the neck is leveled off so that the saddle can accurately be seated. The stump is accurately trimmed to parallel the plane of the saddle-plate, the plate serving as a guide. If, when the rod is hammered home, any gap exists between the stump and end-plate, the nail is elevated about one-half inch and one or two collars are inserted to close the gap (Fig. 4).

As will be demonstrated later, it is most important that any such gap be closed before the insertion is completed and the rod is finally hammered home (Fig. 3, *C*). Several firm blows are delivered to break down small bone prominences that might prevent close contact.

The drill guide is applied to the end-plate, the drill is inserted through it and guided by it through the hole in the axial rod continuing until the outer femoral cortex is penetrated (Fig. 3, *D*).

This step in the insertion procedure requires a drill of the proper size and length and a drill guide. Without a drill guide, blind penetration of the transfixion hole is practically impossible; with it, it is impossible to miss and the procedure takes a minimum of time (Figure 5 shows these useful accessory instruments). When the drill and guide are removed, the pivot rod is directed through the new channel and is tapped into position (Fig. 3, *E*).

A head of proper size is applied and the dislocation is reduced (Fig. 3, *F*). After the operation, plaster-spica immobilization for about two weeks overcomes the occasional tendency of the prosthetic head to dislocate. Exercises are begun promptly and partial weight-bearing is allowed at four to five weeks.

EVALUATION

During the past five years, the transfixion prosthesis has been used by various members of the Mount Sinai Hospital Orthopaedic Staff in forty-eight patients; twenty-seven of these patients were operated upon between April 1951 and June 1954 (Table I). In two of these patients frank suppurative infection developed; this required removal of the prosthesis. These patients are not included in the follow-up study. A third patient was inadvisedly operated upon seven years after the failure of a nylon arthroplasty performed in another institution. Although extrusion of nylon fragments had ceased four years prior to the insertion of the transfixion prosthesis, it recurred promptly after the operation. Persistence of these extrusions and fistula formation required removal of the prosthesis five months after its insertion. A fourth patient could not be contacted for follow-up examination. The remaining twenty-three patients constitute the basis of this interval study. Of the twenty-three patients, ranging in age from sixteen to eighty-six, five were men and eighteen were women. Eight were operated upon for osteo-arthritis and fifteen because of failure of intracapsular fractures to heal.

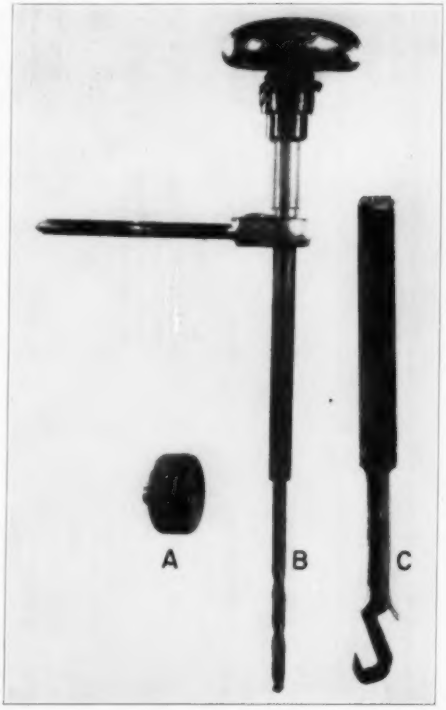

FIG. 5

Useful instruments for the insertion procedure: *A*, drill guide, *B*, ratchet drill of proper gauge and length, and *C*, twister for correction of minor errors in rotatory alignment of main shaft.

TECHNICAL ASPECTS

1. *The Insertion Procedure, Adaptability, and Preservation of Neck Length*

In the first eighteen patients, various anterior and anterolateral approaches were tried, but all were subsequently discarded. All of them required excessive retraction for the adequate presentation of the superior surface of the femoral neck. It was our impression that not only was accurate placement hampered but also that the damage to soft tissue was sufficient to favor infection. The use of the lateral approach has practically eliminated subsequent infection. The incorporation of the McFarland modification, employed in the last five patients of this group and in all subsequent patients, appears to have hastened the return of function of the glutaeus medius and subsidence of the Trendelenburg limp.

Because of the different status of each hip operated upon, the insertion procedure calls for separate judgment in each case. The guiding factors as they appear in the critical analysis of these patients may be summarized as follows:

The ultimate length of the reconstructed femoral neck is determined during the first step of the insertion—the selection of the point at which the prosthetic stem is inserted at the apex of the neck. A careful survey before operation and before insertion is, therefore, of the greatest importance. A large femur, generally one that calls for a long neck reconstruction, presents a neck surface proximally extending some two centimeters medial to the greater trochanter within which this point may be chosen. If the

TABLE I

No.	Pt. Age Sex	Operative Indications	Duration	Medical Complications	Date Incision	Ream	Complications	Follow-up
Ununited Fractures								
1	BH 72 F	Ununited intracapsular fracture; aseptic necrosis	4 mos.		4/51 Anterior		None	5 yrs., 1 mon.
2	UH 50 F	Ununited intracapsular fracture	7 mos.	Severe obesity	6/51 Anterior		None	2 yrs.
3	MT 67 F	Ununited intracapsular fracture	6 mos.	Obesity; hypertension; and mild polyarthritis	6/51 Anterior		Trochanter split; 5 weeks immobilization; protruding stem of pivot rod removed 2½ years	4 yrs., 1 mon.
7	HS 16 M	Ununited intracapsular fracture in previously fused hip	7 mos.		1/52 Antero-lateral	X	None	4 yrs., 5 mos.
8	JM 86 F	Ununited intracapsular fracture; 3 attempts at internal fixation	7 mos.		2/52 Antero-lateral		None	2 yrs., 8 mos.
9	CA 74 M	Ununited intracapsular fracture; total aseptic necrosis	4 mos.	Arteriosclerosis	2/52 Antero-lateral	X	Head too small; 2 yrs. later new head inserted because of intrapelvic migration	4 yrs., 4 mos.
10	SW 61 F	Ununited intracapsular fracture	7 mos.	Sciatica; osteo-arthritis of spine	6/52 Antero-lateral	X	Severe purulent infection; prosthesis removed; hip arthrodesed	
11	EB 60 F	Ununited intracapsular fracture	3 yrs.	Rheumatoid arthritis	6/52 Antero-lateral		Mild thrombo-phlebitis	Not available
12	CF 64 M	Ununited intracapsular fracture	6 mos.		9/52 Antero-lateral		Supracondylar fracture; residual shortening ¾"	2 yrs., 7 mos.
13	MS 69 M	Ununited intracapsular fracture	3 yrs. 2 mos.	Rheumatoid arthritis	2/53 Antero-lateral		Late fracture of prosthesis	2 yrs.
15	AH 80 F	Ununited intracapsular fracture; aseptic necrosis	3 yrs.	Feeble; arteriosclerosis	3/53 Antero-lateral		None	1 yr., 6 mos. Died 8/54
17	SH 22	Femoral head and acetabular fracture (bilat.); Judet prosthesis bilaterally	4 yrs.		3/53 Antero-lateral	X	None	3 yrs., 4 mos.

18	VG 80 F	Old untreated hip fracture unhealed; unknown duration	Unknown	Arteriosclerosis	8/53 Antero-lateral		None	2 yrs., 4 mos. Died 4/55
20	BS 64 F	Ununited intracapsular fracture	8 mos.		10/53 Gibson		None Late fracture of prosthesis; prosthesis replaced	3 yrs., 6 mos.
21	FH 65 F	Ununited intracapsular fracture	14 mos.		1/54 Gibson		None	2 yrs 5 mos.
22	SH 24 F	Fracture-dislocation of the hip; Judet prosthesis	5 yrs.		2/54 Anterior		Severe purulent infection; prosthesis removed Hip fused	
25	AM 73 F	Ununited intracapsular fracture	8 mos.	Blindness; diabetes; neuritis	4/54 McFarland		None	1 yr., 6 mos.
26	EH 71 F	Ununited intracapsular fracture	5 mos.	Mild polyarthritis	4/54 McFarland		None	2 yrs., 2 mos.
Osteo-arthritis								
4	CB 69 F	Unilateral osteo-arthritis, mild stiffness, increasing pain	4 yrs.		9/51 Antero-lateral	X	Subtrochanteric fracture	2 yrs., 1 mon.
5	CH 46 F	Unilateral osteo-arthritis, patient incapacitated by pain	2 yrs.	Osteo-arthritis of spine; unrecognized pre-existing actinomycosis	10/51 Antero-lateral	X	None	1 yr., 5 mos.
6	MB 67 F	Osteo-arthritis in Paget's disease	3 yrs.		12/51 Antero-lateral	X	None	2 yrs., 3 mos.
14	LH 62 F	Failed nylon arthroplasty 7 years previously	10 yrs.		2/53 Antero-lateral	X	Recurrent extrusion of nylon fragments; persistent fistula; prosthesis removed	1 yr., 1 mon.
16	MM 59 F	Painful osteo-arthritis, moderate stiffness	8 yrs.		3/53 Antero-lateral	X	Mild thrombophlebitis right leg	3 yrs., 2 mos.
19	SC 40 F	Aseptic necrosis; increasing pain; etiology unknown	3 yrs.		8/53 Gibson	X	None	2 yrs., 10 mos.
23	CW 54 F	Unilateral osteo-arthritis; severe pain; stiffness mild; etiology unknown	2 yrs.	Psychoneurosis under therapy	3/54 McFarland		None	2 yrs., 3 mos.
24	IR 52 F	Bilateral osteo-arthritis; almost total stiffness	12 yrs.	Opposite hip fused; severe hypertension	4/54 McFarland	X	Trochanter split	2 yrs., 2 mos.
27	RL 47 F	Unilateral osteo-arthritis; constant increasing pain; stiffness mild	4 yrs.		5/54 McFarland	X	Superficial wound infection, no residue	3 yrs.

residual portion of the neck is small, however, its size may impose a limiting factor upon the length of the reconstructed neck. Occasionally the neck stump has been so short that undercutting of the trochanter was necessary for end-plate contact even with the use of collars. In these instances, it was necessary to sacrifice neck length (Case 3, Fig. 11). Figure 6 illustrates the latitude possible in placing of the prosthesis. As will be shown, adequate contact of the end-plate or underlying collars against the stump end must be ensured; this contact must take precedence over long neck length if the reconstruction is to remain stable.

That the limitation of neck length is less than might appear is evidenced by a review of the entire group of patients in whom the prosthesis was used. In all but two patients

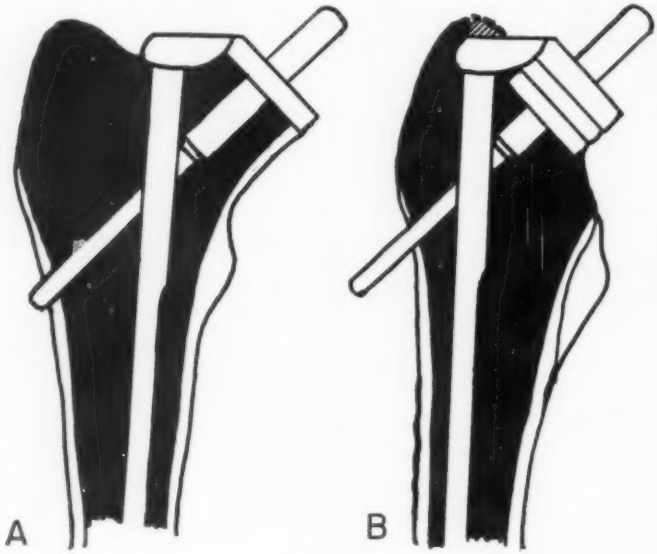

FIG. 6

Range of adaptability: *A*, central placement of the prosthesis when the stump of the femoral neck is long; *B*, lateral placing of the prosthesis when the stump of the femoral neck is short—the undercutting of the trochanter should be noted.

who had hip abnormality on the opposite side, comparison of the lengths of the femoral necks was possible. In one patient, the shortening in neck length amounted to 2.2 centimeters; in the other shortening amounted to 1.8 centimeters. In the majority of patients shortening of the neck amounted to less than one centimeter when compared with the opposite femoral neck. Roentgenographic comparison of the reconstructed hip with the normal or opposite one in each case has revealed a mean variation of only ± 0.59 centimeter. Figures 7 through 10 show the symmetry achieved in several reconstructions. It is believed that this reasonably accurate restitution has been reflected in the consistent return of full abductor function.

It has not been our practice to resuture the hip-joint capsule. After wound closure, the application of a one and a half low plaster spica has been regarded as indispensible. In the patients operated on early in whom the shaft was split during the reduction procedure, plaster immobilization was maintained for five and six weeks. In all other patients, two to three weeks of plaster immobilization was regarded as adequate. No postoperative subluxation or dislocation occurred in these patients.

FIG. 7

Figs. 7, 8, 9, and 10: Prosthetic reconstructions illustrating the approximate accuracy of the restoration of the normal head-to-trochanter interval. Placement of the insertion point of the main stem determines the ultimate neck length.

FIG. 8

2. *Durability of the Prosthesis*

Late fractures of the prosthesis occurred in two patients (Cases 13 and 20) which, in retrospect, appeared to be directly related to inadequate insertion technique. These will be discussed in a following section. Apart from these fractures, there was no mechanical failure of any sort in this group of patients or in any of the patients subsequently operated upon. Thus far, the record would appear to demonstrate the durability of the mechanism, vindicate the multiple piece assembly, and speak for the skill of the manufacturer.

3. *Stability*

Since the transfixion prosthesis depends in large part upon the femoral neck for support, it is important to ascertain whether this structure can be relied upon for this function or whether, as some maintain, it is untrustworthy and prone to deterioration

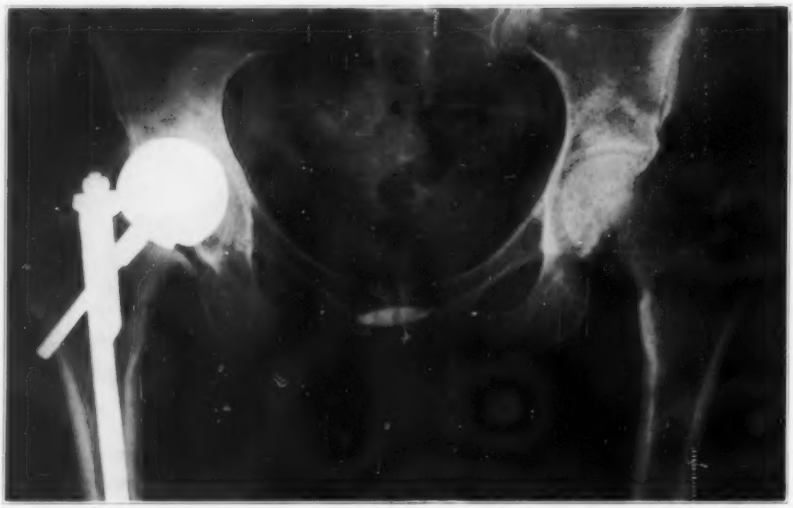

FIG. 9

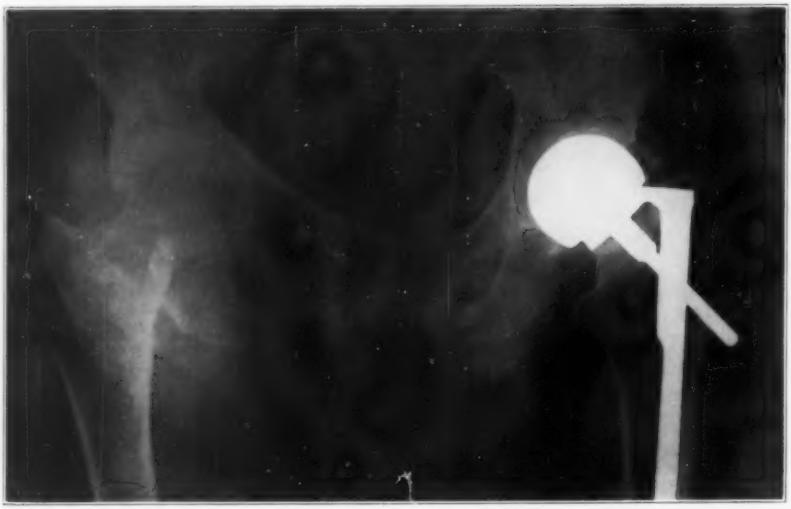

FIG. 10

and eventual absorption. The anterior and anterolateral approaches originally employed made the accurate seating of the end-plate of the prosthesis against the stump difficult. Fortunately, study of the findings in the patients in whom these approaches were used has been most useful in determining the reliability of the femoral neck. Omitting otherwise complicated cases to be later discussed (Cases 5, 6, 8), twenty patients were available for the study of stability.

These patients were grouped according to whether full, partial, or no end-plate-to-stump contact had been surgically attained (as determined by postoperative roentgenogram). In eleven of these patients full or almost full end-plate contact was obtained at operation (Cases 3, 7, 12, 16, 17, 19, 21, 24, 25, 26, and 27) (Fig. 11-A). In the second group, consisting of four patients (Cases 1, 4, 15, and 23), contact had been

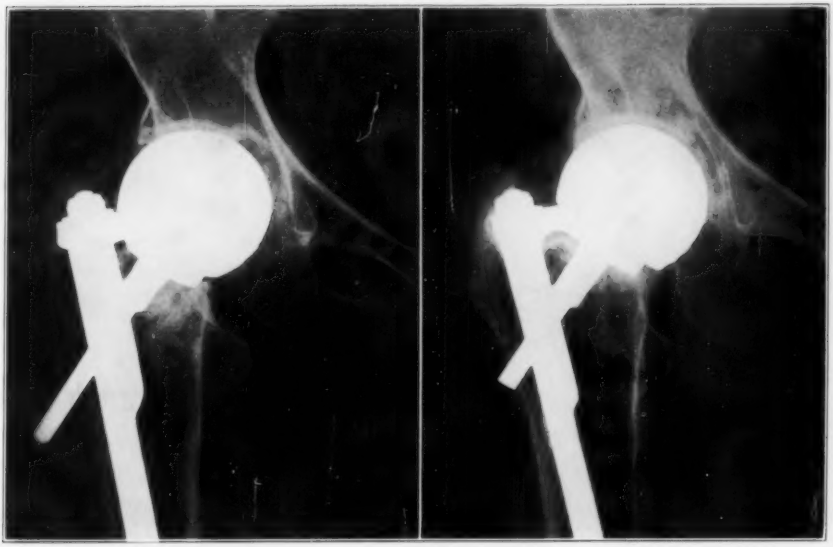

FIG. 11-A FIG. 11-B

Figs. 11-A and 11-B: M. T., age sixty-seven. Prosthesis was inserted four and a half years ago.

Fig. 11-A: Postoperative roentgenogram.

Fig. 11-B: Four and a half years after operation. The prosthetic stability has endured even though there was severe senile osteoporosis and, two and a half years after operation, fracture of the pelvis. Patient walks with a limp and does her own housework. There is occasional ache in the hip on change of position. There is normal strength active motion in all planes, except that flexion is limited to 70 degrees. Extrusion of pivot rod was removed because of tenderness over it.

FIG. 12-A FIG. 12-B

Figs. 12-A and 12-B: B. H., age seventy-two. Transfixion prosthesis was inserted five and one-half years previously for unhealed femoral-neck fracture.

Fig. 12-A: Postoperative roentgenogram. Incomplete but adequate contact of the end-plate to the neck stump was established at operation.

Fig. 12-B: Roentgenogram made five years later. Hip completely asymptomatic. Clinical examination disclosed no limitation or weakness of active hip motion in any plane. Note subsequent rounding off of receded segment of neck stump not subjected to direct pressure. Minimal bone condensation developed at pressure areas. No prosthetic migration occurred in over five years.

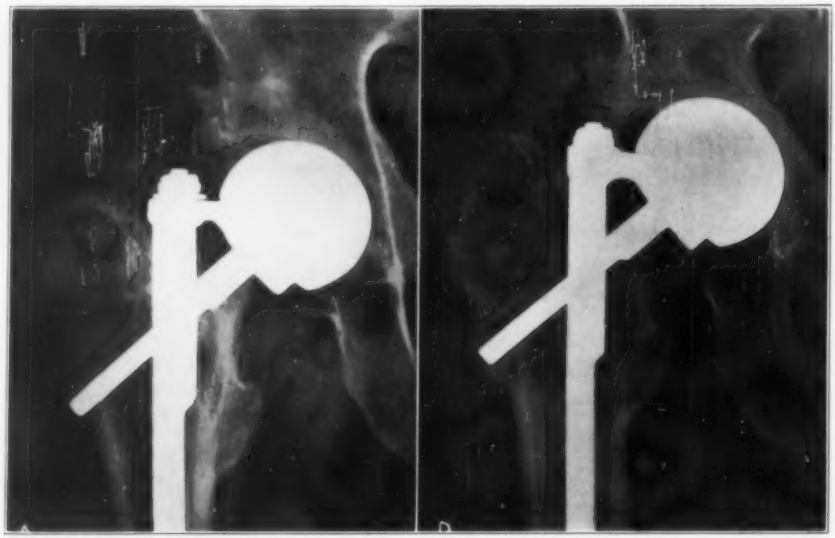

FIG. 13-A

FIG. 13-B

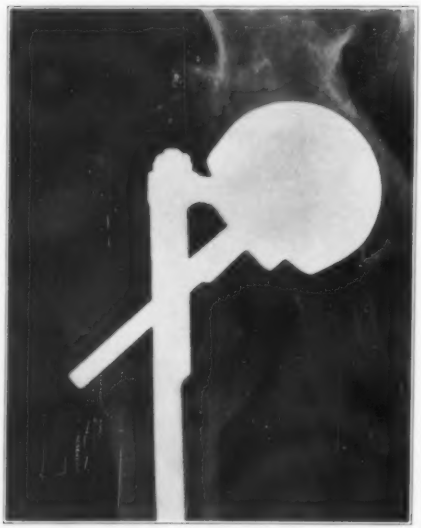

FIG. 13-C

Figs. 13-A, 13-B, and 13-C: Case 9. C. A., aged seventy-four. These roentgenograms illustrate the penalty of inadequate angle-plate contact and the use of too small a prosthetic head. The hip is moderately painful and patient uses a cane.

Fig. 13-A: Postoperative roentgenogram. Note failure of angle-plate contact and small head.

Fig. 13-B: Roentgenogram of hip made one year and nine months after operation. Note deterioration of the neck and central acetabular migration.

Fig. 13-C: Roentgenogram of hip made two years and four months after the replacement of the small head with one of proper size. There has been no increase in acetabular depth since the larger head insertion.

surgically established over at least one-half of the stump-end area (Fig. 12-A). In three patients this contact was above and in one patient it was below. The third group included two patients in whom end-plate contact was almost entirely lacking and one in whom such contact involved distinctly less than one-half of the stump area (Cases 2, 9, 18) (Fig. 13-A).

In each of the eleven patients of the first group, the residual femoral neck had not diminished in substance but had consistently remained and hypertrophied in response to its share of weight-bearing two to five years after operation (Figs. 11-A and 11-B).

In the four patients in the second group, the portion of the neck in contact with the end-plate had also consistently maintained its integrity as seen on the last roentgenograms. The portion of the stump not in contact with the end-plate had fallen further away from the angle plate and had become rounded and atrophic (Fig. 12-A).

Follow-up study of the five patients in Group 3 revealed ultimate failure of femoral-neck integrity when there was either no contact or contact of only a small area of neck stump (Figs. 13-A, 13-B, and 13-C). In one patient (Case 2) inexperience and the extreme

obesity of the patient resulted in surgical failure to attain any contact of the end-plate with the stump surface. Subsequent roentgenograms revealed gradually increased atrophy of the femoral neck and, after a year, its almost total disappearance. The prosthesis had wandered downward into the femoral shaft to the extent of almost two centimeters.

The second instance of minimal stump-to-plate contact (Case 9) also revealed gradual atrophy and withdrawal of the femoral neck. After one year and nine months, the femoral neck had totally disappeared and the prosthesis had migrated downward one centimeter into the femoral shaft (Figs. 13-B and 13-C).

The third patient in Group 3 (Case 18) presented, as seen in postoperative roentgenograms, only a small spur of stump in contact with the upper aspect of the angle plate. Two years later roentgenograms showed the spur to have withdrawn along with the remainder of the neck. The meager demand upon this hip probably accounts for the minimal prosthetic migration downward seen in the roentgenograms two years later.

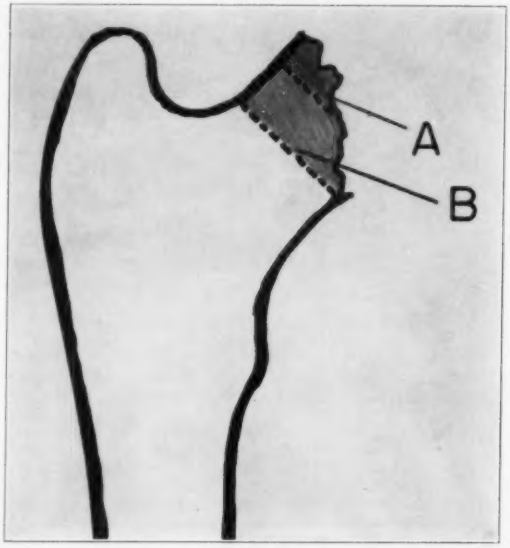

Fig. 14: Diagram illustrating the greater neck support provided by use of higher bevel: *A*, although more end-plate contact is sacrificed by the higher bevel, contact of one-half of the stump end surface area has proved adequate for firm and lasting stability. *B*, the highest level permitting full contact sacrifices supporting neck tissue.

FIG. 14

FIG. 15-A FIG. 15-B

Figs. 15-A and 15-B: C. F., age sixty-four. Roentgenograms show heavy bone condensation engulfing prosthesis.

Fig. 15-A: Postoperative roentgenogram.

Fig. 15-B: Roentgenogram made one and one-half years after operation. There is excellent function clinically.

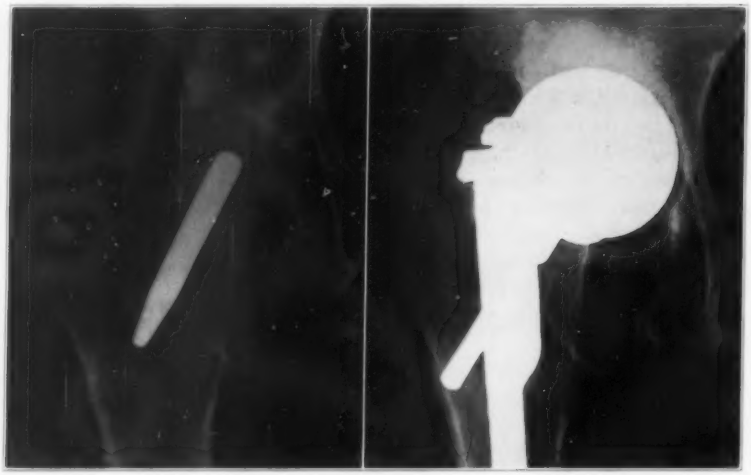

FIG. 16-A FIG. 16-B

Figs. 16-A and 16-B: S. H., age twenty-two. Replacement of inadequate Judet prosthesis by transfixion prosthesis.

Fig. 16-A: Three years after insertion of Judet prosthesis. Note increasing rarefaction about stem and atrophy of the calcar femorale. Bone fragments from the femoral neck lie free in hip-joint capsule. Hip was too painful for weight-bearing. Range of motion was limited by pain.

Fig. 16-B: Three years and four months after removal of Judet prosthesis and replacement with transfixion prosthesis. Note filling in of enlarged bony channel with new bone and returning bone density and calcar. Fixation has been solid with no migration. Patient has no pain in hip. Motion limited in flexion to 90 degrees and in extension to 170 degrees. Abduction is weak, but Trendelenburg sign absent.

The fourth patient in Group 3 (Case 13) is included here even though the author has had no contact with this patient and early roentgenograms are unavailable. According to the history, however, early convalescence was not notable except for the hampering effect of severe rheumatoid polyarthritis which precluded walking without crutches. Almost two years after operation, the patient reported that a sudden click had occurred in the hip when he rolled over in bed. The patient did not consult his surgeon about the episode until four months later; at that time roentgenograms showed a fracture of the lower triangular section of the stem. If the history of the patient is accurate, fatigue fracture would appear to be the most likely explanation of this casualty. Roentgenograms (four months after prosthetic fracture) suggest that the end-plate had been receiving only minimal buttressing from the upper tip of the neck stump. Under these circumstances, full weight-bearing stress was imposed directly upon the stem as a bending strain subjecting it to risk of fatigue fracture.

The fifth patient in Group 3 (Case 20) sustained a sudden fracture of the prosthesis through the saddle three years after operation while reaching for a lamp cord. A complication such as this fracture had been predicted because of the inadequate contact of the end-plate to the stump gained at operation. Examination of the broken segment after the prosthesis had been replaced left little doubt that the breakage was a fatigue fracture —the result of inadequate angle-plate support. Both of the patients (Cases 13 and 20) had been operated upon before the importance of direct end-plate support had been fully appreciated.

These cases offer consistent evidence that, in its response to demand, the bone of the femoral neck behaves just as does bone in other locations. It remains and hypertrophies when pressure (without abrasion) is applied to it and it gradually atrophies and melts away when such demand is insufficient or absent. The femoral neck, therefore,

would appear to be entirely trustworthy for prosthetic support if nonabrasive and well distributed pressure is applied to it. The patients in Group 2 give evidence that the entire stump end is not required for adequate stump-to-plate contact—that one-half or more of the stump surface area is sufficient in order to ensure its integrity for prosthetic support. This information is useful when the residual neck is short and when a "complete bevel" would require the sacrifice of a useful supportive neck segment (Fig. 14).

The third group, although small, suggests that weight-bearing pressure applied to a small surface area of the neck can be excessive and, as in other bones, may result in disintegration and progressive loss of angle-plate support. Contact of the stump end with the plate, amounting to less than one-half of the stump-end area, would appear to provide precarious and vulnerable prosthetic support.

FIG. 17

Case 19, S. C. Roentgenogram made three and one-quarter years after insertion. Prosthesis has been under the constant stress of heavy physical labor. Note minimal reaction of the host femur to the stem.

Since the transfixion prosthesis is designed to gain a large share of its support from the neck stump, it is not surprising that its stability depends on maintenance of the integrity of this structure. Of the twenty patients included in the study of the femoral neck, fifteen in Group 1 and Group 2 and one in Group 3 (Case 18) exhibited no measurable change of prosthetic position during the observation period. At approximately two months after operation, foci of bone condensation, as seen roentgenographically, appeared at areas of pressure. They were first observed at the tip of the neck stump underlying the contact area. A month or so thereafter, they were often detected about the pivot rod at its penetration point through the outer femoral cortex. They were sometimes observed (with less consistency) about the central transfixion zone within the trabecular substance of the femur. In instances when the acetabulum had been reamed, condensation was invariably noted in the acetabular roof. In some instances, condensation areas remained and increased for the duration of the observation period and finally engulfed the entire intraosseous portion of the prosthesis (Figs. 15-A and 15-B). In other instances, areas of condensation slowly receded to be replaced by normal, well aligned, mature, and sturdy trabecular structure. No consistent correlation of this varied bone response with the clinical picture could be elicited. The stability of the bone-to-prosthesis bond obtained by the competent insertions in Group 1 and Group 2 has been entirely sufficient to overcome osteoporosis and severe trauma. Three of the patients (Cases 3, 18, and 25) had severe osteoporosis which undoubtedly played a role in the occurrence of the original

TABLE II

COMPARISON OF POSTOPERATIVE AND LAST X-RAY STATUS

Case		Postoperative X-ray Status			Last Follow-up X-ray Status				
		Head-Trochanter Interval Involved Side (*Centimeters*)	Opposite Side (*Centimeters*)	Fit of Prosthetic Head	End-Plate to Stump Contact	Neck Absorption	Prosthetic Central	Migration Into Femur	Comment
1	B.H.	10.4	10.4		Partial	Area of no contact			
2	U.H.	11.2	11.2		Little or none	Complete		X	No end-plate contact
3	M.T.	9.2	11		Full	None			
4	C.B.	11	10.5	Shallow acetabulum	Partial	Area of no contact			
5	C.H.	10.6	11.1		Full	Area of no contact		X	Indolent infection Paget's disease
6	M.B.	11	11.4		Full	Complete	X		
7	H.S.	9.3	11.5	High false acetabulum	Full	None			
8	J.M.	10.3	10.1		Full	Complete	X	X	Indolent infection
9	C.A.	12	12.2	Head too small; replaced with larger one	Little or none	Complete	X	X	Head too small; no end-plate contact
12	C.F.	10.1	10.4		Full	None			
13	M.S.	Not available				Complete		Fracture stem	Early x-rays unavailable
15	A.H.	11	11.4		Partial	Area of no contact			
16	M.M.	10.7	11.3		Full	None			
17	S.H.		Fused	High false acetabulum	Full	None			
18	V.G.	12.2	11		Little or none	Complete			No end-plate contact
19	S.C.	12	11.3		Full	None			
20	B.S.	11.5	10.5		Slight	Almost complete		Fracture of saddle	
21	F.H.	10	10		Full	None			
23	C.W.	10.4	11		Partial	Areas of no contact			
24	I.R.		Fused		Full	None			
25	A.M.	10.4	10.5		Full	None			
26	E.H.	10.4	10.1		Full	None			
27	R.L.	11.2	11.3		Full	None			

intracapsular fracture. The prosthetic fixation in these patients was not less competent than that in patients with sturdier skeletal structure. The following two cases are illustrative of this stability:

A woman (Case 3), sixty-seven years old, was operated upon four and one-half years ago. She was hypertensive and subject to dizzy spells. Eight months after operation, multiple areas of spinal pain and tenderness developed. Roentgenograms of the spine showed beginning collapse of three thoracic vertebrae and postmenapausal osteoporosis. The patient responded slowly to hormonal therapy, bed rest, and finally treatment by back braces. Although the hip inevitably is involved in this type of bone atrophy, prosthetic stability was not affected and the prosthesis did not alter its position in the femur. After several months, the patient was able to resume her normal household duties.

Two years after operation, while in the course of her housework, the patient became dizzy and fell directly upon the reconstructed hip. The hip area was severely bruised as a result of the impact, and pain was sufficient to require rehospitalization. Roentgenograms disclosed an ipsilateral fracture of the ramus of the ischium and pubis but revealed no damage to the prosthesis or disruption of its relationship with the bone. The patient was able to resume normal activities five weeks after injury. A recent hip roentgenogram (Fig. 11-B) made four and one-half years after operation and two years after the pelvic fractures showed that the hip prosthesis had remained precisely in the position in which it was originally placed. Clinically it is functioning well and there is no residual limp.

A second case history well illustrates the difference in response of the same hip to a well applied Judet prosthesis and subsequently to the transfixion prosthesis.

The patient (Case 22) was a young lady, twenty-three years old. Judet prostheses had been inserted elsewhere three years previously because of fracture-dislocations of both hips and acetabulae sustained in an airplane accident. Hip pain, bilaterally, had increased about six months after operation, and it had continued to increase steadily; pain was worse on the right side. At three years it had become totally incapacitating. Roentgenograms of the right hip (Fig. 16-A) showed considerable atrophy of the skeleton about the prosthesis and acetabulum. The calcar femorale had disappeared, the prosthetic channel had widened broadly, and several loose fragments of the femoral neck lay about the joint. The possibility of prosthetic fracture was suggested.

Operation proved this preoperative impression to be incorrect; instead, although the prosthetis was intact, it was spinning freely in a channel three times its original diameter; there was free motion and laxity in all planes. The device was removed and a transfixion prosthesis was inserted, although the femoral neck consisted of little more than a hollow tube. The postoperative course was smooth and subsequent convalescence proved to be quite painless with reference to the right hip. With the resumption of activity, however, pain in the left hip increased to the extent that the patient pleaded for operation on that side. The left hip was accordingly operated upon almost a year later; it became infected. Removal of the prosthesis and arthrodesis were necessary. Despite this unfortunate interlude, the integrity and stability of the right-hip reconstruction was maintained.

A roentgenogram made three years and four months after the operation (Fig. 16-B) showed that the rarified bone which had surrounded the Judet prosthesis was replaced by firm condensation about the transfixion prosthesis. The broadened channel was no longer discernable and the calcar femorale was returning. There has been no alteration in the position of the prosthesis despite vigorous use of the hip.

Figure 17 illustrates the response of the host femur to a prosthesis that has been *in situ* and under total physical demand for over three years (Case 19).

INSTABILITY

In the twenty-three cases reviewed here it has been previously noted that roentgenographic evidence of prosthetic instability occurred in two of the five patients in Group 3 in whom the prosthesis was inadequately seated at operation. In these patients (Cases 9 and 18) some, but insufficient, contact of stump to the angle plate was attained surgically, and condensation of the contact spur developed after several months. However, in these patients, condensation gradually diminished, the stump finally withdrawing entirely from the metallic plate. Once contact was lost, the neck segment became atrophic and continued to diminish in size. The downward migration of the angle plate was too slow to keep pace with the diminishing neck segment and contact was never re-established.

Two additional but non-specific types of instability were noted in three patients

TABLE III

COMPARISON OF INSERTION ACCURACY WITH LAST CLINICAL AND REHABILITATION STATUS

Pt.	Postoperative End-plate Contact	Latest Clinical Evaluation							
		Date and Duration	Objective						
			Limp	Shortening	Motion (*Degrees*)				
					Flex.	Ext.	Abd.	Add.	Rot.
Ununited Fracture									
B.H. 1	Partial	5 yrs., 1 mon. 5/15/56	None	None	35	180	30	30	full
U.H. 2	Little or none	2 yrs. 6/10/53	Marked	¾ inch	70	180	20	30	full
M.T. 3	Full	4 yrs., 11 mos. 5/24/56	None	¼ inch	70 Bilat.	180	30	35	full
H.S. 7	Full	4 yrs., 5 mos. 5/24/56	Not with shoe correction	2 inches	90	180	30	20	ext. 30
J.M. 8	Full	2 yrs., 8 mos. 10/26/54	Fistula developed.		Prosthesis removed 2 yrs., 4 mos.				
C.A. 9	Little or none	4 yrs., 4 mos. 5/24/56	None	¾ inch	80	170	20	25	55
C.F. 12	Full	2 yrs., 7 mos. 4/20/55		¾ inch (supracondylar fracture)	170	80	20	15	50
M.S. 13		2 yrs., 4 mos. 1/27/56	None prior to prosthesis fracture		60	175	25	15	full
A.H. 15	Partial	1 yr., 6 mos. Died 8/54	Moderate	None	85	170	15	20	full
S.H. 17	Full	3 yrs., 4 mos. 7/6/56	Limp due to high acetabulum and abductor weakness		90	170	35	30	full
V.G. 18	Little or none	2 yrs., 4 mos. 1/27/56	Moderate	None	80	170	15	15	⅔

TABLE III (*Continued*)

COMPARISON OF INSERTION ACCURACY WITH LAST CLINICAL AND REHABILITATION STATUS

	Subjective			Rehabilitation and Comments
	Power	Pain	Weakness	
Comparison with Opposite				
Equal to opposite	Normal	None	None	No economic problem. Patient extremely active physically and gives no thought to hip. Engaged in care of home, charitable endeavors and vigorous shopping activities.
Flexion limited to 20 degrees	Weak in all planes	Marked	Moderate	Pain in hip increasing and constant. Generally uses one crutch, occasionally cane. Patient uncooperative and makes little effort.
Equal to opposite	Normal	None	None	Patient resumed sole care of large household. Complete facility in getting about. Mild polyarthritis.
Flexion limited 40 degrees; internal rotation limited 30 degrees	Normal	None	None	Has walked ten to twelve miles on occasion without discomfort. Employed in vigorous occupation. Athletic counsellor for boys. No complaint. Wears high shoe for shortening.
Equal to opposite	Fair	Moderate	Increasing, generalized	No limp but prefers to walk with cane to relieve weight-bearing pain. Increasing circulatory insufficiency with oedema of both legs at end of day.
All motions limited 5 to 10 degrees	Normal	Slight	Slight	Slight limp due to shortening and arthritis of knee which causes mild pain. Cane for long distance walking. Usual household work.
Other hip arthritic	Moderate	Slight	Moderate	Fracture of stem two years after insertion.
Equal to opposite	Fair	Moderate	Very feeble, generalized weakness	Patient old and feeble. Not working before injury. Complains of moderate pain requiring cane. Died (cardiac failure) one year, eight months after operation.
Opposite hip injured	Weak in abduction	None	None	Cane is used for long walks because of multiple spine injuries and fusion of opposite hip. Full-time employment which requires subway commuting. Four to five flights of stairs climbed daily.
Internal rotation moderately limited	Weak in all planes	Moderate	Increasing weakness	In home for aged prior to injury. No tasks but walks freely with cane as before. Hip moderately painful. Died (pneumonia) two years, eight months after operation.

TABLE III *(Continued)*

COMPARISON OF INSERTION ACCURACY WITH LAST CLINICAL AND REHABILITATION STATUS

Pt.	Postoperative End-plate Contact	Latest Clinical Evaluation							
		Date and Duration	Objective						
			Limp	Shortening	Motion (*Degrees*)				
					Flex.	Ext.	Abd.	Add.	Rot.
B.S. 20	Partial	2 yrs., 7 mos. 5/24/56	None	None	40	185	35	35	full
F.H. 21	Full	2 yrs., 5 mos. 5/14/56	None	None	40	180	35	30	full
A.M. 25	Full	1 yr., 6 mos. Died 1/56		None	110	165	10	20	full
E.H. 26	Full	2 yrs., 2 mos. 5/28/56	None	None	80	180	20	25	full
Osteo-arthritis									
C.B. 4	Partial	2 yrs., 1 mon. 10/25/53	Marked	None	45	180	30	30	full
C.H. 5	Full	1 yr., 5 mos. 3/5/53	Abscess developed.		Prosthesis removed 1 yr., 5 mos.				
M.B. 6	Full	2 yrs., 3 mos. 3/18/54	Marked	1 and ½ inches	85	175	5	20	⅔
M.M. 16	Full	3 yrs., 2 mos. 5/10/56	None	None	90	175	20	25	⅔
S.C. 19	Full	3 yrs., 5 mos. 1/7/57	None	None	45	180	35	30	full
C.W. 23	Partial	2 yrs., 3 mos. 5/10/56	None	None	55	180	20	25	full
I.R. 24	Full	2 yrs., 7 mos. 12/13/56	Slight	None	70	135	10	10	⅓
R.L. 27	Full	2 yrs., 9 mos. 2/11/57	None	None	80	180	30	25	full

TABLE III *(Continued)*

COMPARISON OF INSERTION ACCURACY WITH LAST CLINICAL AND REHABILITATION STATUS

	Subjective			Rehabilitation and Comments
	Power	Pain	Weakness	
Range 5 to 10 degrees greater than opposite in all planes	Normal	Slight	None	No occupation. Patient traveling freely around the world. Occasional ache in hip after walking long distances. No walking aid. Several attacks of sciatica due to disc at L4. Fracture of prosthesis three years after operation. Prosthesis replaced.
Equal to opposite	Normal	Slight	None	Full time business employment and care of home. Slight ache after long distance walking. No walking aid.
Moderate limitation in all planes except rotation	Weak	None	Generalized weakness	In home for aged prior to injury. Resumption of walking not possible because of diabetic neuropathy and blindness. No pain. Died one year, eleven months after operation.
Equal to opposite	Normal	Slight	None	Patient fully occupied in charitable and civic endeavors. Enjoys walking and has walked five to six miles on occasion with no difficulty. Hip aches after such walks. No walking aid.
Gain in Motion				
Moderate gain	Normal	None	None	No complaint of discomfort. Walks normally. No walking aid. Left city and could not be followed after two years and one month.
Increasing loss of abduction; slight gain in other motions	Fair in all planes	Moderate	Moderate	Complaint of increasing pain about hip after initial period of almost a year of total relief of symptoms. Has resorted to cane and sometimes a crutch. Caring for small household without help.
Moderate gain in all planes	Normal	None	None	Patient walking long distance without pain or fatigue. Carrying on with all household duties. No symptoms.
Moderate gain in all planes	Normal	None	None	Patient engaged in heavy physical labor. Feels he has been completely cured. No symptoms.
Moderate gain in all planes	Normal	Slight	None	Occasional recurrences of pain during psychotic episodes. Otherwise pain-free and gainfully employed. No limp. No walking aid.
Slight gain in all planes	Normal	None	None	Patient very active managing chicken farm and home. Some ache after long walks in woods. Gait moderately improved in accordance with limited gain in hip motion.
Moderate gain in all planes	Weak abduction	None	None	Patient very active. Walks unlimited distances; prefers to use cane for long walks. Slight limp due to abductor weakness. She has no pain.

(Cases 5, 6, and 8) who were excluded from the previous stability study. In two patients (Cases 5 and 8) deterioration began and slowly continued after an initially smooth postoperative convalescence. The cause of the unsatisfactory progress was the development of a fistula two years and four months after operation in one and the formation of an abscess one year and five months after operation in the other. Although infection had been suspected in these patients because of the consistently rapid sedimentation rate, it was not definitely demonstrable until finally revealed by suppuration. Temperature and blood counts had been repeatedly within normal limits in both instances and repeated aspiration of different areas failed to indicate suppuration. The first infection, due to actinomycosis, was believed to be pre-existing; the other, due to staphylococcus, was considered to be an operating-room infection. Both caused prosthetic migration and skeletal rarefaction.

A second and rather surprising cause of prosthetic instability was observed in one patient (Case 6) who was operated upon because of painful osteo-arthritis of the hip secondary to florid Paget's disease. The prosthetic migration that ensued appears to have accompanied the spread of Paget's disease to the femur.

It is noteworthy that each instance of stability failure presented a clear, well defined cause for that failure. No prosthetic instability occurred that was not directly attributable to inadequate prosthetic support, to infection, or to Paget's disease.

STABILITY IN YOUTH

Because of the special problems involved, the question of prosthetic stability during the growth period has been approached with great caution. Would the more rapid turnover of bone elements during growth favor migration of the prosthesis? What is the effect of a static femoral head upon acetabular growth and adaptation? Until answers to these questions are available, it would appear prudent to sharply limit the use of prostheses in children and adolescents. One youth of sixteen (Case 7) is included in the present series. In this instance, the insertion of the prosthesis appeared justifiable because of non-union of a fracture of the femoral neck in a previously fused hip. Four years after operation roentgenograms showed no significant alteration in the position of the prosthesis despite the vigorous activity of the patient as an athletic recreational director for younger boys.

A fifteen-year-old patient was subjected to the insertion of the prosthesis one year ago. A favorable interval result is too early to include in the present report.

STABILITY AT THE HIP JOINT PROPER

It may be pertinent under the heading of stability to consider briefly the stability of the hip joint proper, even through the transfixion prosthesis has contributed no innovation in this area except for the preservation of neck length. Up to the present time, no noteworthy problems have been experienced with the prosthesis-to-acetabulum relationship. As might be anticipated, the acetabulum has exhibited deepening and widening as a result of the rarefaction of infection (Cases 5 and 8) and of the rapid bone metabolism of Paget's disease (Case 6). One additional instance of deepening of the socket followed the insertion of a prosthetic head one centimeter smaller in diameter than its natural enormous predecessor (Case 9, Figs. 12-A, 12-B, 12-C). The special manufacture and insertion of a replacement head of correct size two years after the original operation confirmed the source of the trouble. The acetabular migration was totally arrested during the observation period of two years and four months after the second operation. As with the prosthesis-to-femur relationship, it would appear that ample surface contact area of at least normal size is required to diffuse excessive pressure. The problem of postoperative subluxation or dislocation commented upon by other observers has not occurred in these cases except in one instance (Case 22) of extreme joint distension by purulent effusion.

Perhaps the preservation of the head-trochanter interval suffices to diminish the risk of this complication.

CLINICAL EVALUATION

Although the twenty-three cases discussed from a technical aspect comprise a small and exploratory clinical series, their study has been valuable in suggesting the principles underlying successful application, in indicating the clinical results that may be anticipated, and in pointing out certain errors involved in the development of a new technique. It is necessary, however, to bear in mind the constant demand for endurance in a prosthesis and to realize the tentative nature of the conclusions drawn from this limited experience.

The excellent interval result that may be achieved by use of the prosthesis is well illustrated by the clinical course of the first patient in whom the transfixion prosthesis was utilized (Case 1). The patient aged seventy-two was operated upon almost five and one-half years ago because of failure of internal fixation to maintain position four months after intracapsular fracture. Her sister, with whom she lives, had numerous complaints about the continual vigorous activity of the patient, her constant stepladder climbing at home, and her rigorous social, shopping, and charitable tours. Examination revealed no pain or limp or limitation of motion in the involved hip. There was no shortening. Muscle power was normal in all planes, including abduction; there was no asymmetry seen when the patient walked up or down stairs. The extremity operated upon could be identified only by the scar and by means of roentgenograms (Figs. 12-A and 12-B). Roentgenograms showed the complete maintenance of stability throughout the follow-up period and the almost normal and mature trabecular structure of the host bone.

This clinical survey considers separately the factors of pain and limp, range of motion and power, and capacity to return to pre-illness status (Table III).

PAIN AND LIMP

Survey of Table III indicates that fifteen of the twenty-three patients had either no pain, or, in three at their last examination, mild ache on change of position or after excessive activity. Two patients (Cases 3 and 23) complained of residual pain for longer than the usual postoperative period. The symptoms in these patients were relieved by appropriate measures.

Use of a cane by three patients of this group (Cases 3, 17, and 24) was indicated because of instability, not because of pain.

Four of the twenty-three patients (Cases 2, 9, 15, and 18), at their last examination, complained of moderately severe pain on weight-bearing sufficient to require a cane for three and a crutch for one. As the table indicates, the prosthesis in three of these patients had been inadequately seated at operation; in the fourth, seating of the prosthesis was of doubtful security. To this group may be added another patient (Case 13) whose hip became painful after the fracture of the prosthesis two years postoperatively. Increasing sustained pain developed in three patients after an initially smooth convalescence (Cases 5, 6, and 8). In two, the cause proved to be indolent infection; in one the cause was prosthetic migration due to Paget's disease. If this last group in which symptoms were attributable to extraneous complication is omitted, there seems to be a sharp correlation between accurate seating, prosthetic stability, and subsequent pain.

MOTION AND POWER

Study of the gain or return of hip mobility (Table III) revealed no clear correlation with the technical procedure but rather with the pre-existing condition of the hip. The patients operated upon because of unhealed fracture of the hip demonstrated, at the last examination, rapid and practically complete return of the pre-existing range of motion;

this had been maintained during the observation period. Even in the presence of instability due to inaccurate seating or to indolent infection (Cases 2, 8, 9, and 18) passive motion was generally uncompromised, although in these patients the limits of motion were painful and active power had diminished.

The uncomplicated prosthetic reconstructions performed for osteo-arthritis were distinctly less successful with respect to gain in mobility. Although the small number of cases in this group does not justify significant conclusions, it may be stated that all of the patients had rapid return to pre-existing motion, but they showed limited gain beyond this point. One striking exception was a patient (Case 7) who, after seven months of bone fusion, demonstrated unusual gain in motion (90 degrees of flexion) after four and one-half years and is still steadily improving. It would appear, however, that while the pain of osteo-arthritis is intrinsic, long-standing stiffness becomes fixed by extra-articular contracture and is not amenable to great improvement through the insertion of a prosthesis. While the stiff osteo-arthritic hip would appear to gain only moderately in motion after the insertion of the prosthesis, the preservation of pre-existing motion and the relief from pain would justify the use of the prosthesis, especially when the pre-existing range of motion is useful. Except in the cases of instability of the prosthesis previous noted, the return of muscle power has presented no noteworthy problem. In patients with ununited fracture and osteo-arthritis, abduction has been slow to return. Although the Trendelenburg sign has been generally overcome two to four months after operation, abductor weakness has been demonstrable by examination for four to twelve months after operation. The duration of the preoperative hip condition would appear to play a major role in this delay as anticipated. The patients in whom higher acetabular transposition was required (Cases 7 and 17) had not attained complete abductor power at the time of their last examination. However, power was ample to overcome the Trendelenburg sign in both instances in six to eight months.

REHABILITATION AND ECONOMIC STATUS

From the standpoint of rehabilitation, the seven patients with intracapsular fracture, ranging in age from seventy to eighty-three, must be separately considered. Two of these patients, in a home for the aged, beset with various medical conditions, presented no opportunity for economic rehabilitation. However, two patients of this group considered themselves as well as before hip injury and three became entirely self-sufficient although, because of moderate pain, they required the aid of a cane for walking.

Of the nine remaining patients in whom the transfixion prosthesis was used for treatment of hip fracture, seven had been actively engaged in charitable or gainful employment prior to injury. Five of these patients have fully resumed their prior occupation or have undertaken equivalent work. Two patients were unable to do so, one because of indolent infection which required removal of the prosthesis (Case 8), and one because of inaccurate seating followed by migration of the prosthesis (Case 2). Two patients were forced temporarily to give up work because of fracture of the prosthesis (Cases 13 and 20).

Of the eight patients with osteo-arthritis, six have resumed their former activities with relief from pain and with variable improvement in hip mobility. One failure followed operation in a patient with Paget's disease (Case 5); the second failure occurred in a patient with indolent infection which required removal of the prosthesis.

COMMENT

Although the number of cases in this pilot study is small and interpretation must be done with caution, striking correlation between prosthetic seating, prosthetic stability, and ultimate clinical competence and performance is evident.

Accurate seating of the transfixion prosthesis with adequate contact of the end-plate

to the stump in patients with normal bone structure in whom there is no infection has consistently yielded survival and hypertrophy of the contacting femoral-neck stump, prosthetic stability, and sustained painless or almost pain-free performance for the duration of the period of observation. The enduring favorable result would appear to depend upon the capacity of the transfixion prosthesis to apply adequate non-abrasive and non-shearing supportive pressure upon the end of the neck stump and the consequent persistence and stabilizing support of the femoral neck. Accurate insertion is essential.

In patients in whom significant symptoms have developed after the insertion of a prosthesis, a clearly identifiable cause has been always apparent. The major cause of prosthetic instability and decreased mobility has been stump absorption due to inaccurate prosthetic seating or infection. The sharp decline in both of these complications in patients operated on later in the study followed abandonment of the cramped surgical exposure provided by the various anterior and anterolateral approaches originally employed. The posterolateral approach provides ample room for accurate seating of the prosthesis without the excessive and tissue-damaging retraction that, in earlier cases, seemed to predispose to infection.

The return of full abductor power in almost all of the patients in whom the operation was successful has shown the capacity of the transfixion prosthesis to approximate normal length of the femoral neck. The soft bone of florid Paget's disease would appear to be unsuitable for prosthetic insertion but even a marked degree of senile osteoporosis has presented no barrier to prosthetic stability or to enduring clinical performance.

While final judgment must be deferred, these experiences with the transfixion prosthesis lead to the belief that its design is capable of yielding stability and lasting competence and performance. The achievement of these objectives requires careful choice of proper soil and accurate performance of the insertion procedure.

1. Ponseti, I. V.: Pathomechanics of the Hip after Shelf Operation. J. Bone and Joint Surg., **28**: 229–240, Apr. 1946.

The Principles of Hip-Socket Arthroplasty*†

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The more than thirty different types of arthroplasty reported in the literature are based on one of three main principles. Two are well known and have been applied in the treatment of a wide variety of conditions. The oldest is the principle of enclosing the head of the femur in a membrane, cap, cup, or mold. The most recent is replacement of the upper end of the femur with a prosthesis. The method least well known and never perfected for routine clinical use is the principle of resurfacing the articular surface of the acetabulum by means of a socket deliberately attached to the pelvis. The method referred to in this paper as hip-socket arthroplasty is an adaptation of the third method and is based on the assumption that:

1. The soft tissue in the acetabular fossa favors the retention of a joint cavity.

2. Less than half of the femoral head lies inside the structure of the acetabulum, and the socket should be as shallow as in the normal hip so as to allow the neck to extend from the pelvis.

3. The stability of the joint is sustained chiefly by the action, tone, and balance of muscles and not by an artificially deepened acetabulum. The evidence for this observation is that the hip will retain its stability after the excision of the capsule and ligaments, if it is immobilized in abduction for six weeks to allow the muscle attachments to heal. The joint can dislocate in paralytic conditions in which muscle balance has been lost and in which the ligaments, labrum, and capsule are intact.

4. Only old eburnated articular cortex, osteophytes, and a minimal amount of bone should be sacrificed from either side of the joint.

Terminology

The most important advance in the modern history of arthroplasty was made by Smith-Petersen[21, 22, 23], who formulated the terminology, technique, and practical application of the method known as mold arthroplasty. Smith-Petersen suggested the term *mold* in order to indicate that the function of the implant is to guide the process of regeneration of a new joint. The terms *cup* or *cap*, however, have been substituted in general usage. The name *hip socket* was selected for the arthroplasty described in this communication because it is descriptive and serves to differentiate this procedure from those in which appliances that rest on the head of the femur are used.

Surface of Motion

Smith-Petersen's mold arthroplasty results in a system in which motion is possible on two surfaces: between cup and acetabulum and between cup and head of the femur. The motion is chiefly between the head and the interior of the mold. Perhaps for this reason, Smith-Petersen designed his mold with a flare or flange around the rim. A small increment of motion is gained between the surface of the mold and the deepened acetabulum. In roentgenographic examinations of patients with successful results and in open examination

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† Read at the Annual Meeting of the Western Orthopedic Association, Phoenix, Arizona, November 1, 1956.

of those subjected to revision, the mold was found to be embedded in the deepened acetabulum and adherent to the pelvis by fibrous tissue and bony overgrowths that had formed as early as two months after the operation. For this reason, it is reasonable to assume that a Vitallium socket might be well tolerated if it was attached to the pelvic (the stationary) side of the joint from the very beginning of the period of healing following an arthroplasty.

Aufranc reported that he now uses a true-arc mold, by which motion takes place chiefly between the mold and acetabulum rather than inside the mold. This creates a system of motion such as that obtained with the caps designed by Venable and Stuck or the concentric molds designed by Adams and functions very much like a femoral-head prosthesis. Rehn reported an experiment in which he placed a plate with a burr-like convex side against the acetabulum. The late Dr. Coonse and recently Gaenslin attached "shallow cups" to the acetabulum with screws. Haboush cemented a cup to the acetabulum with dental acrylic and combined it, as did Gaenslin, with a prosthesis for the head of the femur. There is little evidence, however, to support the contention that it is either necessary or desirable to sacrifice the femoral head in order to produce a successful arthroplasty.

Regeneration of New Joint Surfaces

To restore painless motion to an ankylosed joint, hip-socket arthroplasty initiates a series of proliferative connective-tissue reactions similar to those seen following mold arthroplasty [13, 22]. These reactions listed in the order of their appearance are: fibroplasia and fibrochondroplasia, precipitation of ground substance and formation of fibrinoid, mucin, and mucinous fluid, chondrogenesis, osteogenesis, regression of scar, and periarticular ossification. It is remarkable how near these processes can come to regenerating a joint surface in instances in which the joint has functioned successfully for full weight-bearing with a good range of motion. In a subsequent communication this subject will be presented on the basis of material obtained from revisions studied in the light of the newer knowledge of the histochemistry and physiology of connective tissue.

MATERIALS AND METHODS

Anatomical dissections were done on twenty-five cadavera in order to review the anatomy of the soft parts inside and outside the hip joint and pelvis. The specimens were fixed in Jores' solution, frozen, sectioned with a bandsaw, and embedded in plastic (Selectron 5003). The hip joints of 100 dried skeletons were measured in order to design a hip socket that could be attached to the pelvis. The innominate bones were measured with calipers and depth micrometers.

A non-corrosive metal (Vitallium) hip socket and five special surgical instruments were designed for the purpose of producing in the reconstructed hip an opening below the center of the joint.

The operative technique presented in this report is based upon the performance of forty-eight operations, including five re-operations. The evaluation of the results of the method is based upon observations of the first twelve patients examined between two and three years after the operation.

The revision operations were studied, and samples were obtained from various parts of the new joint. Histological sections were stained with hematoxylin and eosin, azure for cytological structure, toluidin blue for metachromasia, McManus-Hotchkiss for mucopolysaccharides, Mallory's azan or phosphotungstic acid for collagen, Meyer's muci-carmine for mucin, and Foot's or Wilder's stain for reticulin.

ANATOMICAL AND BIOMECHANICAL CONSIDERATIONS

For the purpose of describing hip-socket arthroplasty and the reasoning upon which it is based, the structure of the human hip joint may be reviewed briefly:

Pelvis: The mechanics of the bony arches of the human pelvis are such that the weight of the torso is transmitted to the femoral heads along a spiral line of dense stress-oriented bone known as the arcuate line.

Acetabulum: The acetabulum projects from the pelvis and constitutes a relatively shallow receptacle for the head of the femur. The articular surface forms a horseshoe-shaped platform and a surface area with minimum friction, minimum depth, and maximum strength for articulation with the head of the femur. In walking, during the swing phase of motion of the non-weight-bearing side of the body, the lower extremity hangs from the acetabulum by the head of its femur. A concave shelf-like facet is provided on the posterior inferior portion of the acetabulum for this purpose. The bony rim of the acetabulum, when supplemented by the cotyloid labrum, forms a socket with the depth of a hemisphere. It is not a perfect hemisphere, however; the normal acetabulum is more than one millimeter longer than it is wide.

Femoral head: The femoral head is not a perfect sphere. Because the radius of the curvature of the meridian is more than 1.5 millimeters greater than the radius of the curvature of the equator, it is a rotational ellipsoid. The femoral head rotates on its long axis during the swing phase of flexion and derotates during extension.

Femoral neck: The length of the neck (and head) of the femur forms the beam of a trestle placed at an angle which is mechanically ideal for the function of supporting the trunk. The weight of the torso is not borne vertically on the femur or in the direction of the angle of the neck of the femur (125 degrees) but in the line of the medial cord of stress-oriented bone trabeculae in the interior of the head and neck of the femur. This, according to Inman's calculations, lies at an angle of 167 degrees.

Ligamentum teres, pulvinar acetabulae, and synovial fluid: The acetabular fossa contains the "pulvinar" which is composed of loose connective tissue, fat, and the attachments of ligamentum teres, all of which are covered with synovial membrane. The function of the synovial membrane is to produce synovial fluid to wash and lubricate the head of the femur inside the joint. In flexion, the fat pad and ligament are drawn into the joint space. In extension, the soft parts are pressed from the joint space back into the fossa. The excursion of the soft tissue in and out of the joint space is an important factor in the formation of fluid films for lubrication of the surfaces in motion. The incongruity of the ellipsoid surface of the head and the arc of the acetabulum also promotes lubrication and offers less resistance and less wear and tear than would occur if the surfaces were perfectly flat or congruent [3].

Blood supply: The parietal capsule of the hip joint is a relatively avascular structure. The ligamentum teres and the interior of the bone structure of the femoral neck contain a number of small blood vessels. The visceral capsule contains both large and small blood vessels including the articular branches of the medial circumflex femoral artery to the head of the femur. The parietal capsule should be transected, to disarticulate the joint, near its pelvic attachments and not near its femoral attachments where it blends with the visceral capsule.

Retinacula of Weitbrecht: This structure lies on the posterior side of the femoral neck partly inside and partly outside the visceral capsule and embraces the femoral capital epiphyseal line. It should not be disturbed if it is at all possible because it forms an aqueduct for the blood supply to the superior vital weight-bearing portion of the femoral head [26].

Stabilizing mechanism: Maximum stability is present when the hip is in extension, the head of the femur is screwed home deep into the acetabulum, and the joint surfaces are fully congruent. Stability diminishes when the head is unscrewed and drawn lateralward out of the acetabulum and the joint is in flexion [31]. The glutaeus medius and its accessory muscles are dynamic stabilizers of the hip joint during walking. The stabilizing mechanism before and after arthroplasty is observed by means of the Trendelenburg test.

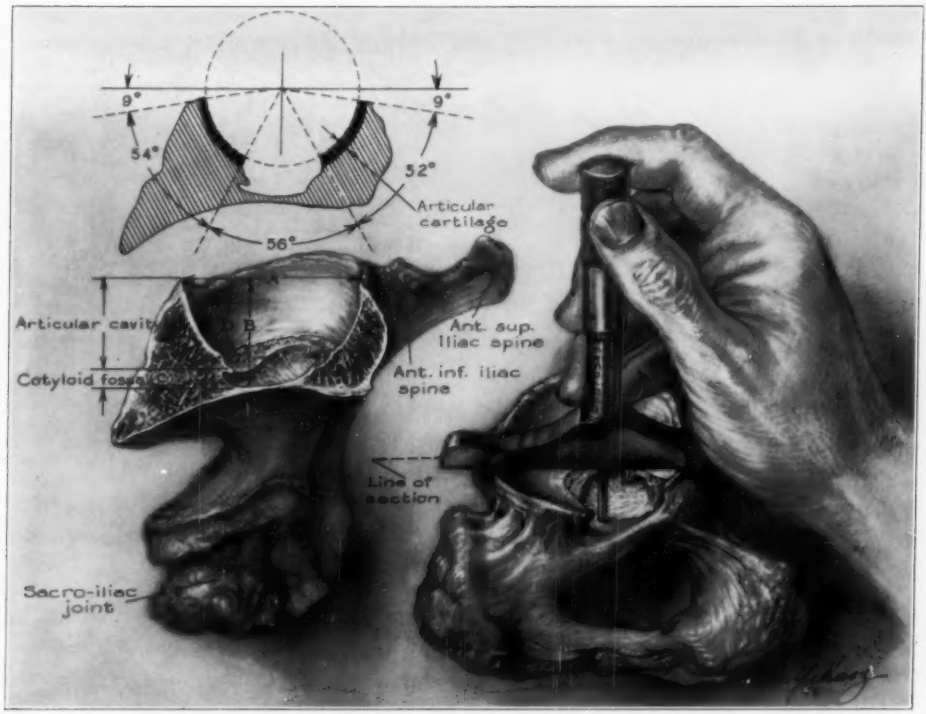


FIG. 1

Artist's drawing of the innominate bone in cross section (upper left) showing that the acetabulum can contain only 18 degrees less than a hemisphere; thus, less than half of the femoral head lies inside the bony structure of the joint, approximately 56 degrees of the hemisphere in this plane is covered not by bone but by the soft parts in the cotyloid fossa, and only 102 degrees of the arc bears the weight of the entire human torso. Drawing of a cross section of a dried bone specimen of the pelvis (lower left) showing the radiating stress lines of the trabeculae in cancellous bone and the recessed position of the cotyloid fossa. An inferior and lateral view of the same specimen (lower right) shows the plane or line of section and the position of a micrometer used in this study to make measurements of the depth of the cotyloid fossa. The fossa (*B*) was normally one-eighth to three-sixteenths of an inch deeper than the articular surface of the platform (*D*).

This test is positive if any of the following conditions are present: (1) subluxation or abnormal excursion of the head of the femur on the rim of the acetabulum, (2) atrophy or weakness of the glutaeus medius or maximus muscles, (3) adhesions of fascia from trauma or arthritis, (4) shortness of the neck of the femur which reduces the length of the lever arm of the hip and the effective pull of the glutaeus medius mechanism, and (5) pain.

Muscles in the region of the hip: The hip joint is enclosed in and moved by an outer mass of large muscles and an inner mass of small muscles. The inner mass crosses the joint in close relationship to the parietal capsule in an arrangement analogous to that of the "musculotendinous cuff" of Codman. The inner mass or *musculotendinous sleeve* of the hip joint, as it will be termed in this report, consists of tendons and bellies of the small deep periarticular muscles. The tendons of this group of muscles should be repaired because their function is to hold the head in the shallow socket and to stabilize the joint when the hip is abducted or unscrewed in flexion.

Innervation: The obturator nerve is responsible for pain referred from the hip to the thigh and knee and is the most important pathway of pain perception before or after arthroplasty. Hardly any nerve fibers have been traced to the hip joint from the femoral nerve except a few small inconstant branches to the anterior parietal capsule that follow the medial circumflex femoral artery. The dorsal aspect of the hip joint is innervated

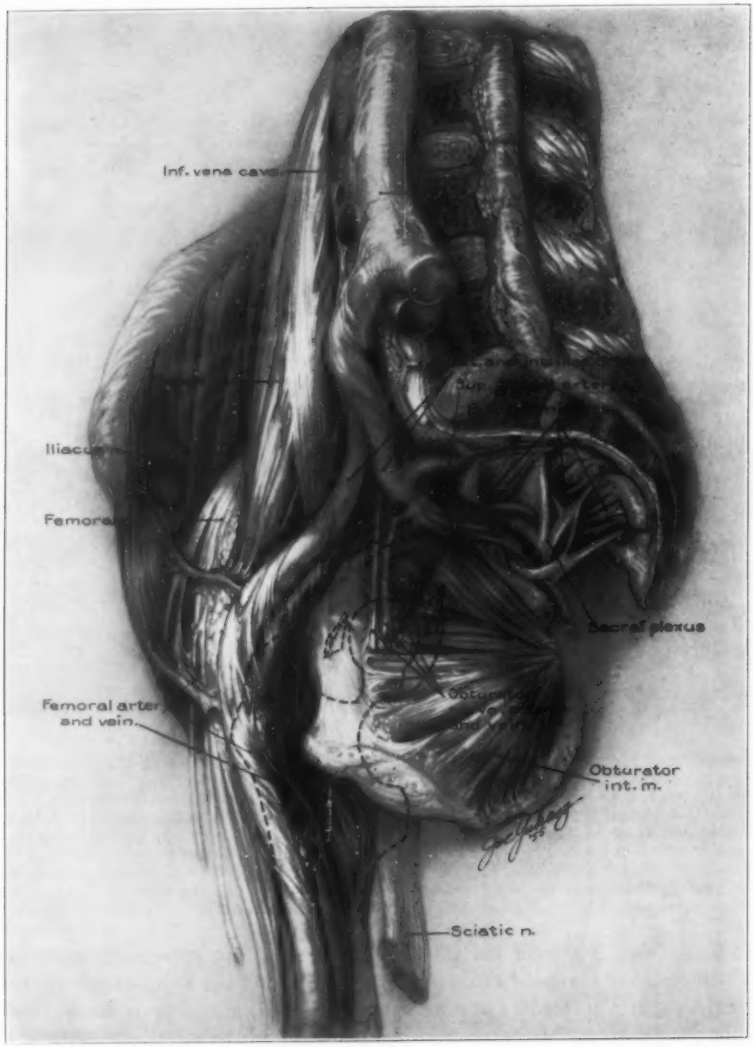


FIG. 2

An original drawing of an actual dissection of the major blood vessels, nerves, and muscles inside the true pelvis. The obturator nerve and vessels pass between the anterior and posterior shoe nails and are protected by the belly of the obturator internus muscle. The femoral artery, vein, and nerve lie anterior and medial to the position of the socket. The position of the external iliac artery and vein and the sacral plexus is posterior and medial. The hip joint lies in a triangular area between the two major groups of large blood vessels and nerves supplying the anterior and posterior parts of the lower limb. The tips of the shoe nails should be cut off one-eighth to one-fourth inch, however, as a precaution in patients in whom the acetabulum has been deepened by reaming or by disease.

by nerves from the sacral plexus and small high branches of the portions of the sciatic nerve proximal to the ischiadic foramen (Figs. 1 and 2).

HIP-SOCKET ARTHROPLASTY

The surgical procedure of hip-socket arthroplasty consists in: (1) use of the postero-lateral approach to obtain extensive exposure of the acetabulum, (2) capsulectomy and

synovectomy to relieve pain, (3) cheilotomy to remove intra-articular obstacles in the range of motion, (4) section of the musculotendinous envelope to relieve periarticular adhesions, and (5) implantation of a non-corrosive metal hip socket.

Description and Effect of the Hip Socket

A cobalt-chromium nickel alloy (Vitallium) which is inert in body fluids was cast in steel dies in a form designed to replace the *articular surface of the acetabulum* including the cotyloid labrum. It is open in the inferior portion to simulate the cotyloid fossa and incisura. The purpose of the opening in the inferior portion of the socket is twofold:

1. It forms an area of communication between the convex side and the incisura and prevents a joint cavity from forming behind the socket.

2. It allows space for organizing blood clot, later granulation tissue, and finally a heavy cord of fibrous tissue, similar to a ligamentum teres, that serves (as seen in revision operations) to bind the inferior portion of the head to the incisura.

Motion and friction upon the surface of the interarticular fibrous tissue presumably produce mucinous fluid like that formed in a pseudarthrosis or adventitious bursa.

The lunate shape of the socket is intended to bear all the weight that is normally borne on the rim and platform of the acetabulum. The superior area of the socket is markedly wider (50 per cent greater in surface area) than the corresponding part of the articular surface of the average acetabulum to provide a broad area for pressure against the soft cancellous bone that is being remodeled against metal.

Three shoe nails, three-fourths of an inch long and three-sixteenths of an inch square at the base extend from the convex surface of the socket. The thickness of the human pelvis in the areas of the insertion of the shoe nails measured from five-eighths to one and one-fourth inches. The nails are slightly tapered, shaped like obelisks, beveled at the tips, and are self-impacting in bone tissue as is the traditional nail used for fastening a horseshoe to the hoof. The nails are parallel to each other and are placed in an equilateral triangle, being tangent, not radial, to the convex surface of the mold. The direction of the shoe nails is ideal when it is parallel to the 167-degree stress lines in the interior of the femoral neck. This automatically places each nail in the direction of the stress-oriented bone trabeculae in the ilium and the linea arcuata. The nails should not protrude more than one-eighth of an inch through the cortex of the true pelvis. The anterior or posterior nail (rarely the superior nail) may penetrate the pelvis if the acetabulum is abnormally deepened by disease or by excessive surgical reaming. The anterior nails should, therefore, be reduced in length one-fourth of an inch or more by cutting off the tip with a Steinmann pin-cutting tool before the socket is inserted in any patient with a thin-walled acetabulum.

Anatomical Considerations Determining the Size and Shape of the Socket

By measuring with Vernier calipers the diameter of the acetabulum of 100 innominate bones, the range of the size in both male and female was found to be from one and three-fourths to two and five-sixteenths inches. By means of a screw micrometer, the depth of the acetabulum was measured; it was found that there are always two levels: (1) the level of the platform of the horseshoe-shaped articular cartilage and (2) the level of the cotyloid fossa. (The level of the platform has usually been destroyed by erosion, eburnated, and moved to the level of the fossa in patients with degenerative joint disease.) The range of the normal depth of the cotyloid platform was from seven-eighths to one and three-sixteenths inches. The level of the center of cotyloid fossa was from one-eighth of an inch to one-quarter of an inch deeper than the platform. The bony contour of the acetabulum is infinitely complex and asymmetrical; nowhere does it form a true arc. In order to produce a joint with a true hemispherical shape, the acetabulum had to be enlarged by reaming; it was necessary to remove only enough bone so that the socket could fit into it smoothly with bone on all sides.

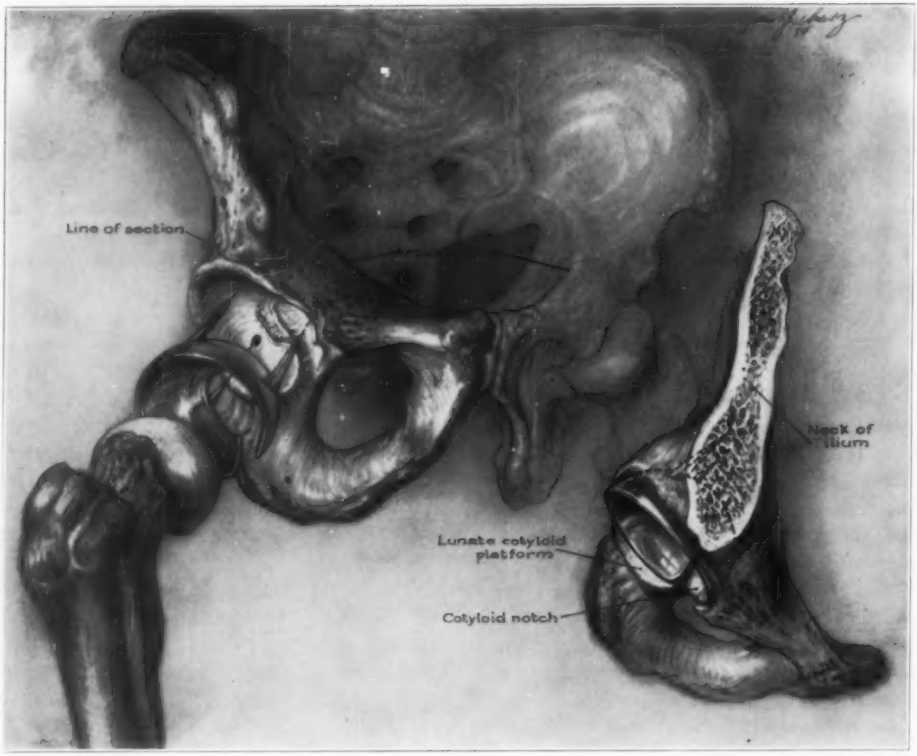


FIG. 3

Exploded view of the hip joint and hip socket (left) showing the anatomical relationships of the pelvis, arcuate line, sacrum, sacro-iliac joint, and lumbosacral vertebrae. The hip socket is shown (right) in place in the acetabulum viewed from above through the line of section. The cortex of the neck of the ilium is extremely dense and thick where it crosses the arcuate line.

The hip socket was made for preliminary trials in six sizes: one and seven-eighths inches, one and fifteen-sixteenths inches, two inches, two and one-sixteenth inches, two and one-eighth inches, and two and three-sixteenths inches in diameter. However, at open operation two sizes, one and seven-eighths inches for the female and two inches for the male, were found to fit all but two of the first forty-eight patients in whom hip-socket arthroplasty was done. All sizes were cast .075 to .085 inch in thickness. The inside surface was polished to a mirror surface or better. The outside surface was vapor-blasted to a satin finish. By means of high polishing, the socket could be reduced to a thickness of .070 inch.

Preoperative Determination of the Size of the Socket

Roentgenographic measurements of the diameter of the head of the femur were obtained within a range of one-eighth of an inch accuracy with the aid of the Colcher-Sussman pelvimeter. In actual practice, however, the hip socket that was finally selected for the individual was determined by trial and error after reshaping and reaming the head on the operating table.

Colcher-Sussman pelvimetry can also be used to measure the thickness of the pelvis in unusually small patients in whom it may be anticipated that it will be necessary to shorten the shoe nails (Fig. 3).

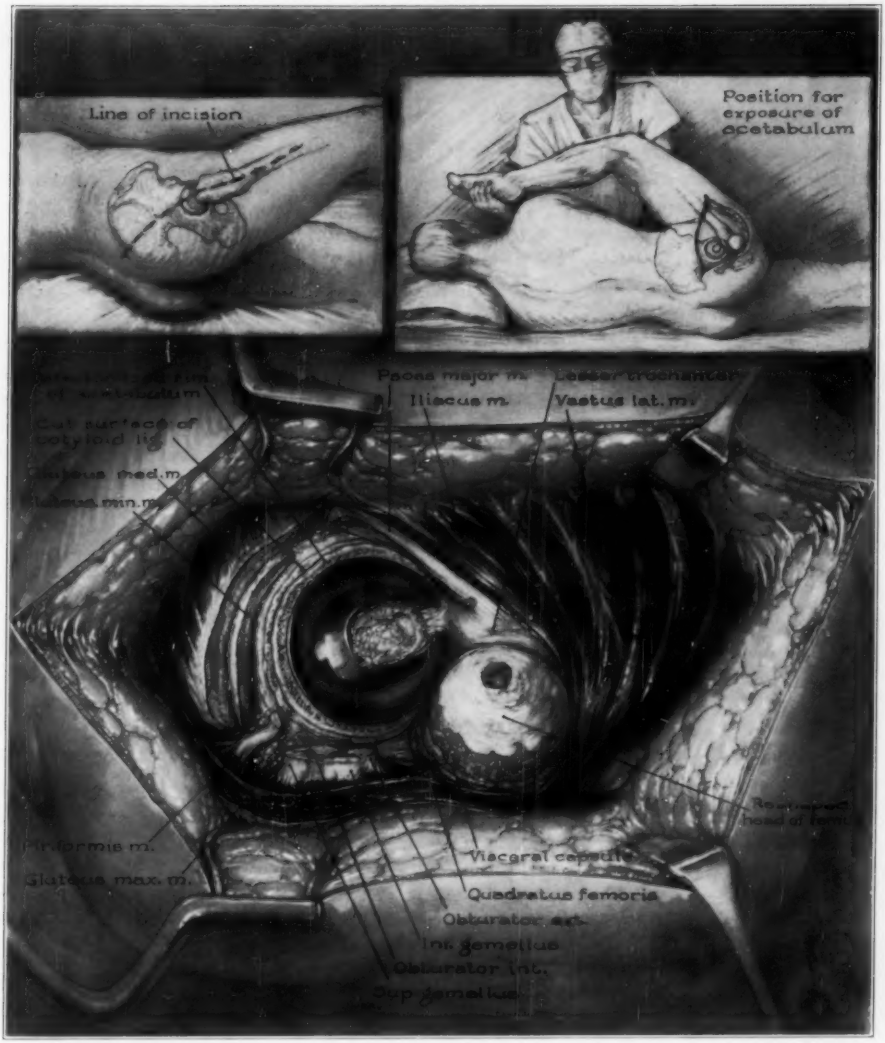


FIG. 4

Artist's drawing (upper left) shows the line of incision of the Gibson approach. The joint is disarticulated by extreme flexion, adduction, and external rotation until the medial aspect of the foot faces upward as shown in the picture on the upper right. Halftone drawing (below) illustrates the surgical anatomy of the hip, with the head of the femur reshaped and the hip socket correctly in place.

SPECIAL INSTRUMENTS

In addition to all the instruments ordinarily used for mold arthroplasty, five special tools are necessary for the specific requirements of hip-socket arthroplasty: (1) *a jig or locating socket* to determine the correct alignment of the hip socket, the congruity of the acetabulum and the convex surface of the socket, and the points of insertion of the socket shoe nails; (2) *a trident broach* or trephine to perforate the dense articular cortex of the acetabulum; (3) *a trident awl* to make tapered channels through the cancellous bone of the acetabulum; (4) *socket-holding tongs* to introduce the socket; and (5) *a driving tool* to tap the socket and the nails gently into tight contact with the acetabulum. A circular

shelf has been added at the end of the handles of the broach and the awl to supply a surface that can be struck retrograde with a mallet in order to withdraw the instruments whenever they become wedged in bone.

OPERATIVE PROCEDURE

The operation is performed by means of a posterolateral exposure in which is combined the approaches of Von Langenbech, Kocher, and Gibson[11, 18, 26]. The incision is made in the sagittal line of the upper third of the thigh and greater trochanter and is extended across the lateral aspect of the hip to the posterior superior spine of the ilium. The fascia lata, from the middle third of the femur to the greater trochanter, is split in two parts; one part is retracted anterior to the greater trochanter and one part is retracted posterior to the greater trochanter. The glutaeus maximus muscle is split in the line between the tip of the trochanter to the posterior superior spine of the ilium. The glutaeus medius and piriformis tendons are divided just proximal to their attachments to the trochanter, a stub being left for repair with sutures. The reflected head of the rectus femoris, the iliacus, the glutaeus minimus, and the small, short external rotator muscle tendons (excluding the quadratus femoris) are similarly transected and retracted. The joint capsule and large ligaments are excised or cut around near the rim of the acetabulum. Only as much of the diseased synovial membrane is removed as can be done without injury to the visceral capsule.

The hip joint is disarticulated with ease and without force when the musculotendinous sleeve of the hip joint has been transected on three sides: anterior, superior, and posterior. Any attempt to dislocate the joint and to expose the head of the femur without completing this step increases the difficulty of obtaining good exposure of the acetabulum and of the operation as a whole. When there has been a previous operation on the hip, there is always dense scar enveloping the joint; it is often necessary to spend a great deal of time carefully excising adhesions or scar and bony overgrowth before it is possible to disarticulate the hip easily. To avoid use of undue force, it is sometimes desirable to osteotomize the rim of the acetabulum; *this is not done, however, unless it is absolutely necessary because it encourages periarticular ossification.*

The head of the femur is retracted simply by placing the hip in extreme flexion, adduction, and external rotation. All parts of the acetabulum and head are fully accessible except the inferior transverse cotyloid ligament and the cotyloid notch. Because of the tendency of soft parts to bulge into the inferior portion of the acetabulum, the only difficulty of the posterolateral approach is with retraction of muscle tissue at the inferior angle of the wound. This is not a serious problem for an experienced surgical team of one surgeon and three assistants. One assistant has the sole duty of holding the extremity in position for good exposure; one holds Hibbs or narrow Deaver retractors; and the other serves as first assistant and is free to devote himself to the job of maintaining hemostasis.

Sculpturing and Fitting the Head

Osteophytes around the margin of the head are trimmed away with a thin osteotome. A new spherical-shaped head is produced simply by grinding and polishing the deformed head with Murphy or Smith-Petersen cup reamers. To encourage growth of new cartilage it is necessary to erase the old eburnated articular cortex. This is an arduous task and it is impossible to perform well with ordinary surgical raspatories. In order to do the job thoroughly, it is necessary to use a coarse large-tooth wood rasp. Dead bone, found in cases of avascular necrosis, is removed with an osteotome and by deeper reaming. However, every possible bit of the viable bone of the head and neck of the femur is retained. The hip sockets are tried on for size until one is selected that fits smoothly and revolves easily in place around the head. The correct size usually fits so that its inside diameter is approximately one-sixteenth of an inch greater than the outside diameter of the newly sculptured head.

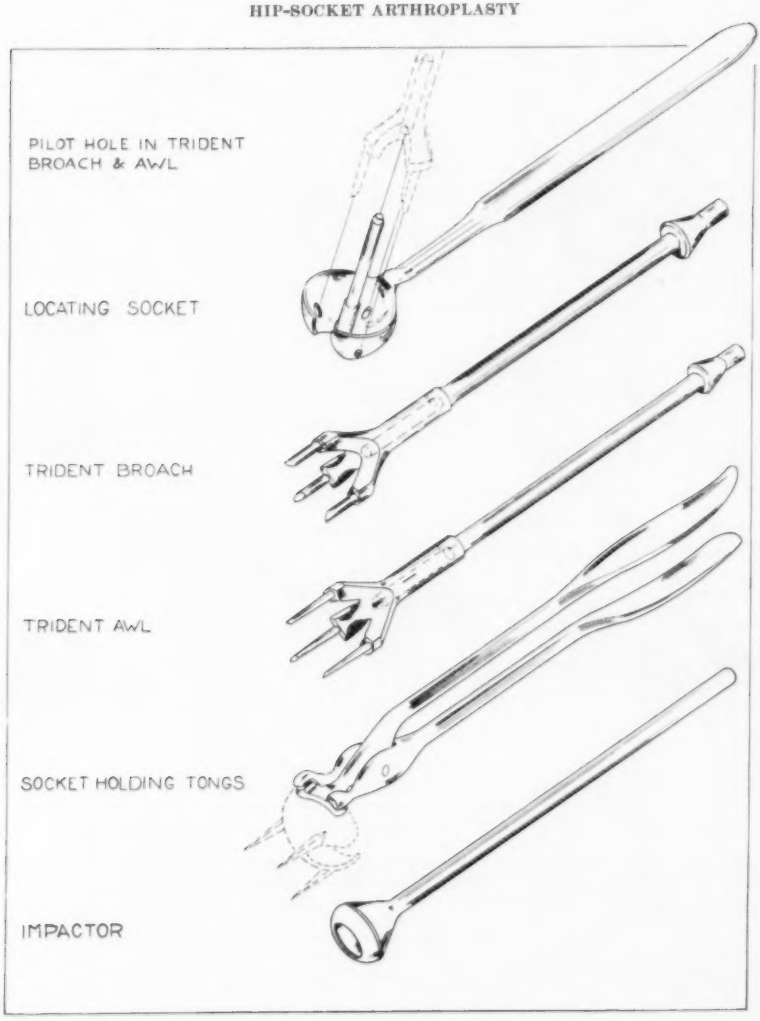


FIG. 5

Five instruments necessary to produce a hip-socket arthroplasty.

Fitting of the Acetabulum

The convex surface of the socket must fit smoothly against bone and receive all the pressure of weight-bearing. The shoe nails merely control rotation and should not bear weight. As mentioned previously, the acetabulum must first be broadened slightly in order to convert it from its normal form (the shape of receptacle for a rotational ellipsoid) to the shape of a perfect hemisphere before the socket can fit into it. This step removes diseased articular cartilage, cortex, and osteophytes at the same time. This is accomplished very easily with the use of co-axial reamers. This type of reamer cuts shavings of cartilage and bone by means of thin convex-cutting blades that cut like a skiving tool. It can greatly reduce the effort and time spent on this most important step of preparing the acetabulum.

The acetabulum is prepared further as follows:

1. A locating socket is placed in it to verify the correct size and to determine the proper position and alignment of the hip socket. The locating socket is simply placed over

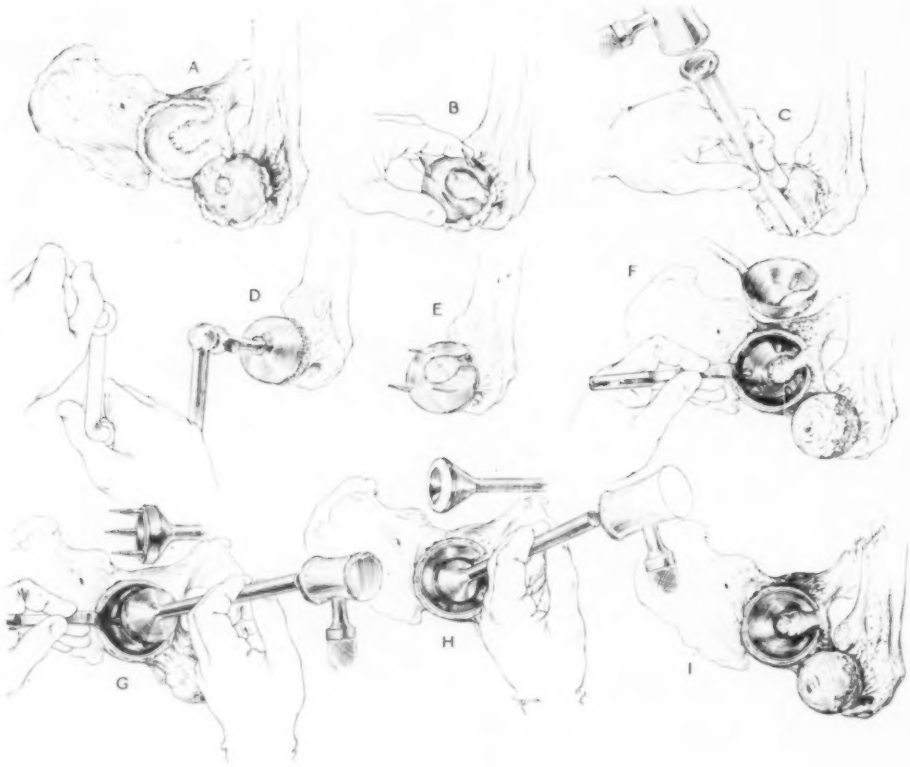


FIG. 6

Nine steps showing the surgical procedure used for hip-socket arthroplasty; *A*, the hip is disarticulated; *B*, a socket is tried on for size; *C*, the osteophytes are trimmed away; *D*, the head is reshaped and made smooth with cup reamers or Murphy reamers on a Hudson brace; *E*, a socket that fits smoothly and allows free motion in all directions is selected; *F*, the locating socket is placed in the acetabulum with the open center overlying the cotyloid fossa and is aligned with the cotyloid notch; *G*, with the aid of the holes in the locating socket, channels are made in the innominate bone for the shoe nails by introducing the trident broach so that it perforates the hard bone of the articular cortex and the tapered trident awl so that it penetrates the spongiosa; *H*, the socket shoe nails are placed in the opening of the three channels with the aid of socket-holding tongs and are gently tapped into place with the tephlon-covered impactor; *I*, the hip socket is in the correct position when it fits tightly against the articular platform, its open center being adjacent to the cotyloid notch.

the cotyloid platform with its notch overlying the cotyloid notch and its anterior rim adjacent to the anterior margin of the acetabulum; the posterior and superior margins of the locating socket are aligned adjacent to the acetabular rim.

2. The position and direction of the hip-socket shoe nails are established with the aid of a *trident broach* introduced through three holes arranged in an equilateral triangle inside the locating cup. The teeth of the broach are beveled toward the center of the acetabulum so that the cutting edge will perforate the slope of the dense (often sclerotic) articular cortex without fracturing it. The diameter of each tooth is slightly less than the width of the base of the shoe nail. This tool is driven in only one-fourth of an inch.

3. The full three-fourths of an inch depth of the shoe-nail channel is reached and the penetration of the inner cortex of the pelvis is accomplished with a tapered trident awl. This is driven into the locating spocket to the hilt. The use of the broach before the awl is necessary because the articular cortex at the opening of each channel is dense compact bone that will not spread and can bend the awl so that it is very difficult to dislodge from

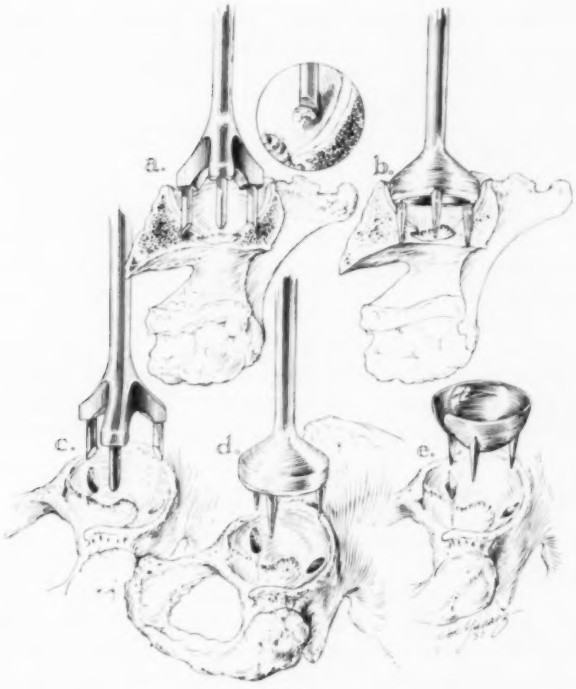


FIG. 7

Drawings to show the action of the tools and socket. The correct depth of the insertion of the broach is shown (*a*). The broach cuts a curled flap of bone out of the dense articular cortex. The correct depth of insertion of the awl is demonstrated (*b*). The broach produces an oval-shaped opening for the base of each shoe nail (*c*). The awl produces a tapered channel through the spongiosa (*d*). The shoe nail of the socket converts an oval opening to a diamond-shaped opening (*e*). In cross section, the tapered channel is the shape of a square. The impaction of a tapered square nail in a tapered round channel holds the socket securely in the bone tissues of the pelvis.

the pelvis. In patients with protrusio acetabulae or in patients in whom deep reaming has been done in a previous operation, the awl is introduced only half length and the shoe nails are reduced to one-half inch in length by cutting them off with a wire-cutting tool. It is reassuring to know that the muscles inside the true pelvis are at least one-quarter of an inch thick and that the tips of the shoe nails are so blunt that they may penetrate the intrapelvic cortex one-eighth of an inch to three-sixteenths of an inch with safety.

4. The hip socket is introduced into the acetabulum with the aid of hip-socket holding tongs. This tool provides the surgeon with a handle with which to direct, to tilt, and to rotate the hip socket in order to place each shoe nail in its channel.

5. The hip socket is *gently* tapped into the depth of the acetabulum with the aid of a driving tool. The square nails cut broadside into the round channels and become tightly impacted in cancellous bone. The driving tool is covered with tephlon in order to prevent scratching of the mirror finish of the lining of the socket. At this point it should be mentioned that it is relatively easy to dislodge the socket by placing a periosteal elevator under it inside the cotyloid fossa and levering it up. This should not be done, of course, unless an error has been made in the placement of the socket. The socket and tools are designed, however, so that with experience, increased skill, and knowledge of the surgical anatomy of the hip harm cannot be done to the patient by a surgeon who attempts to do

the operation. Roentgenographic control should be used in the operating theatre in every case until the surgeon is thoroughly oriented with the position of a hip socket correctly placed in the acetabulum and with *the shoe nails estimated to be in marked valgus with respect to the angle of the neck of the femur.*

The Angle of the Shoe Nails

To be tolerated without stress the broach and awl and the shoe nails of the socket should be placed in the direction parallel to the stress-oriented cancellous-bone trabeculae in the femoral neck and ilium. A joint disorder of long standing usually is associated with stress lines accommodated to either coxa valga or coxa vara. As a rule after the femoral head and acetabulum have been reamed, the shoe nails and the socket should be placed in the angle of the normal neck of the femur (125 degrees) in patients with coxa vara, in the moderate valgus position (167 degrees) in patients with a relatively normal angle, and in extreme valgus position (more than 167 degrees) in patients with coxa valga. The hip is functionally in the position of coxa valga whenever the head must be reamed away, the tip of the trochanter removed, and the glutaeus medius tendon transplanted distalward on the shaft.

Re-articulation of the Joint and Method of Closure of the Wound

The joint is re-articulated by *carrying the head of the femur around the anterior inferior rim.* This is the only way it can be replaced in the new joint with ease. The congruity and range of motion of the arthroplasty is then tested with all parts of the wound retracted in order to give full vision to the surgeon. In patients with rheumatoid arthritis or hypertrophic arthritis associated with rheumatoid arthritis or in patients with joints excessively scarred by previous surgical operations, the wound is closed by suturing only the glutaeus medius tendon, glutaeus maximus fascia, and fascia lata, without suturing of the deep structures. In patients with degenerative joint disease, that is, chiefly an intra-articular condition, the musculotendinous sleeve, including each of the small tendons, is repaired until the wound is closed anatomically and tightly in layers. When the operation and closure is done without any subperiosteal exposure of bone on the pelvic side of the joint, there is little or no periarticular ossification (Figs. 4, 5, 6, and 7).

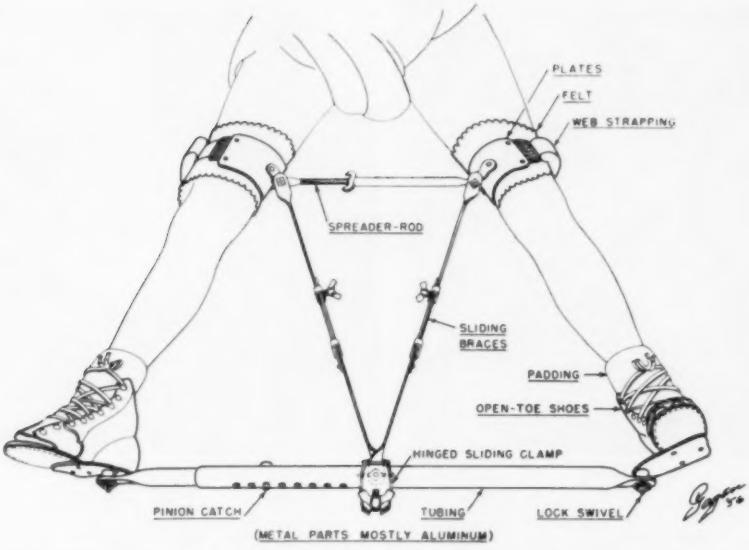
POSTOPERATIVE CARE

The postoperative treatment of the patient following hip-socket arthroplasty is as follows:

1. Both hips are maintained for two weeks in an abduction splint (especially designed for hip-socket arthroplasties) equipped with boots and thigh cuffs in order to hold the hip in wide abduction and internal rotation and yet allow the patient to move the joint immediately and to sit up or to be turned face down in bed.

2. After two to three weeks, this arrangement is used at night only, pillows or sandbags being used to retain abduction during the day from the third to the sixth week after the operation. Quadriceps and gluteal setting exercises are prescribed as early as the first day after the operation.

Convalescence and program of exercises: The postoperative program of exercises described by Smith-Petersen [23] and Aufranc was employed with the exception of only one phase and that was the omission of traction-suspension. The emphasis was on earlier active non-weight-bearing exercises with crutches. No special apparatus seemed necessary because the patients were able to perform without assistance. Crutch ambulation with very slight weight-bearing was possible after six weeks. Full weight-bearing was withheld for six months on the assumption that a fibrous covering should be allowed to form undisturbed over the femoral head. Painless walking without any support was possible after one year (Fig. 8).



ADJUSTABLE ABDUCTION SPLINT WITH THIGH CUFFS

FIG. 8

Abduction splint with thigh cuffs designed for postoperative immobilization of patients with hip-socket arthroplasty. The splint allows the patient to sit up in bed and flex and extend the hip joint in the abducted position. The joint is also held in internal rotation without difficulty in this apparatus for a period of three weeks.

CONTRA-INDICATIONS FOR HIP-SOCKET ARTHROPLASTY

In the presence of congenital dislocation of the hip, paralytic conditions, fresh trauma, active infection of bone, or neoplasm, hip-socket arthroplasty should not be done. Active rheumatoid arthritis and Marie-Strümpell disease are not favorable conditions for the performance of arthroplasty. The operation is also not suitable in cases of degenerative joint disease resulting from acetabular dysplasia, anteversion of the femoral neck, and conditions causing eccentric excursions of the femoral head on the pelvis when the joint is in flexion. The hip socket should be removed and replaced by bone grafts and internal fixation should be inserted in order to obtain arthrodesis in all instances in which the joint does not move freely at the conclusion of the operation.

PRECAUTIONS, TECHNICAL DIFFICULTIES, AND COMPLICATIONS

Various complications were encountered in the first forty-eight hip-socket arthroplasties. Only one (fracture of a shoe nail) was specifically related to the hip-socket arthroplasty itself. All of the others were those that might be expected in a certain percentage of cases following any major operation on the hip joint. The impression that a surgeon receives from experience with hip-socket arthroplasty is that the operation, in comparison with cup arthroplasty, femoral-head replacement procedures, or arthrodesis, is just as safe and in many ways actually *more easily tolerated* by the patient.

Periarticular ossification: New-bone formation almost invariably occurred to some extent in the soft tissues around the joint. It has also been observed by this writer after simple fractures and fracture-dislocations of the hip and after various surgical operations involving the acetabulum [26]. A small amount of periarticular ossification apparently is not incompatible with a good functional end result either with respect to satisfactory motion or relief of pain. It is believed, mainly from clinical impressions, that (1) some diseases,

FIG. 9-A

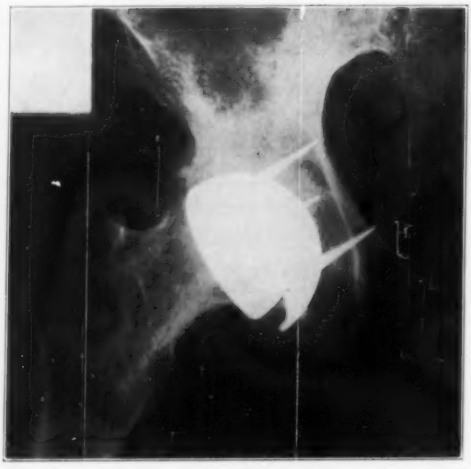


FIG. 9-B

Fig. 9-A: Anteroposterior roentgenogram showing degenerative joint disease or malum coxae senilis of the hip joint in a woman sixty-eight years old (Case 1).

Fig. 9-B: Anteroposterior roentgenogram showing a hip-socket arthroplasty between two and three years after the operation (Case 5).

FIG. 9-C

Frog-leg lateral roentgenogram, showing the amount of abduction and flexion that was possible with use of the hip socket. A cap of bone has formed around the tip of the shoe nail as indicated by the arrow (Case 5).

fresh fractures, and certain individuals, particularly young individuals, are predisposed to produce pericapsular and ectopic ossification, (2) friction and motion of tendons against metal induces bone formation, (3) the lifting of periosteum at the joint margins causes formation of exostoses, and (4) exercise or weight-bearing allowed too early and too vigorously accelerates the process. If the hip can be disarticulated, as described in this paper, *without* osteotomy of the rim of the acetabulum and raw bone is not exposed

FIG. 10-A

FIG. 10-B

Fig. 10-A: Roentgenogram showing avascular necrosis of the femoral head and degenerative joint disease three years after a fracture of the neck of the femur in a man thirty-nine years old (Case 8).

Fig. 10-B: Roentgenogram of the hip joint approximately two years after a hip-socket arthroplasty operation. The dead bone was reamed away from the superior portion of the head. The tip of the trochanter was excised and the glutaeus medius tendon was transplanted to the lateral tubercle of the femur. Note the degree of abduction that is possible.

on the pelvic side of the joint, there is much less tendency to extra-articular ossification.

Hemorrhage: In the posterolateral exposure the wound may be quite dry when the soft parts are in the position of exarticulation and then quite flooded with blood when the limb is returned to normal position. In order to achieve perfect hemostasis, the wound should be retracted on all sides and a second search should be made in order to ligate any branches of the circumflex femoral arteries that were constricted and not bleeding while the hip was in the disarticulated position.

Wound infection: In two cases in which the hip muscles and joint were scarified by previous operations and sepsis, there was recurrence of infection. In two instances, there were superficial wound infections in previously uninfected patients; these were associated with hematomata in the lower region of the wound and disappeared promptly after the blood clot was evacuated. Ordinarily, suppuration of hip wounds is due to mixed infections. Sometimes *Bacterium coli* contamination of the skin is the cause; this is avoidable by thorough preoperative preparation of the perineum, preoperative bowel or systemic chemotherapy, and rigid aseptic technique during the operation.

Sciatic-nerve injury: Special precautions are necessary to avoid stretching the sciatic nerve. Temporary weakness of dorsiflexion of the foot occurred postoperatively in one patient in this series in whom there had been previous sciatic-nerve damage associated with a war wound and shrapnel injury of the hip. When the hip is exarticulated by the posterolateral approach, the thigh is telescoped and the nerve should be slack, but, as is the vastus lateralis muscle, it is twisted on itself. Injury to the nerve will be avoided

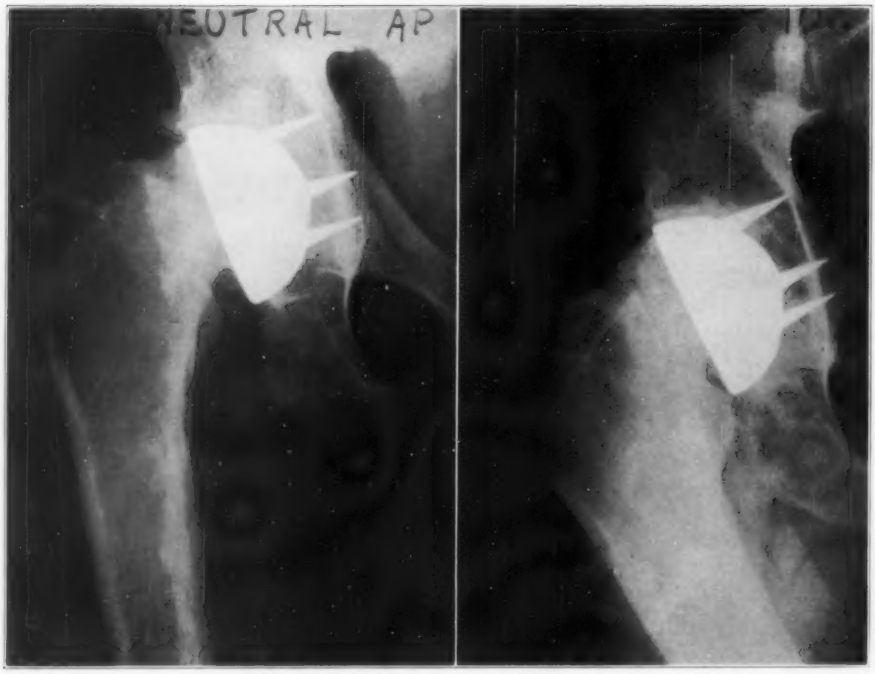


FIG. 10-C FIG. 10-D

Fig. 10-C: Roentgenogram of the hip joint as seen in neutral position with the knees together.
Fig. 10-D: Roentgenogram of the hip joint as seen in the position of maximum adduction. Note the smooth articular cortex newly formed on the superior portion of the head.

if the assistant holding the extremity will move the hip gently to and fro and not hold it in any one position too long. The position of adduction, flexion, and external rotation should be necessary for only a few minutes at a time during the operation. The surgeon and his assistants thus must be gentle and must be aware of the position of the sciatic nerve at all times and with every change in the position of the limb.

Creaking: The head was fitted with a socket that was too tight in two patients; these heard and felt creaking in the hip joint while doing straight-leg-raising exercises. Fortunately, the creaking disappeared within two months. Creaking can be avoided if the socket is correctly fitted one-sixteenth of an inch larger than the head.

Bending or breaking of a shoe nail: The first designs of the socket were made with the shoe nails tapered to a point. In one patient, the tip of the superior nail was observed to bend slightly when driven against the hard cortical bone of the inner pelvic wall. In another patient, the superior shoe nail broke at a point three-sixteenths of an inch from the base. The patient complained of vague pains in the region of the hip joint immediately after the fracture of the shoe nail. This arthroplasty was revised, and the acetabulum was reamed to produce a better fit for the socket. To prevent this complication, two special measures were adopted: (1) the base of the shoe nail was increased from five thirty-seconds to three-sixteenths of an inch and the shape of the nail was changed from a tapered point to the form of an obelisk with a round tip; (2) co-axial reamers were obtained for this operation to prepare the acetabulum so that the weight of the torso would be evenly distributed on the convex surface of the socket and not on any part of the shoe nails. Neither breaking nor bending occurred in any patient in whom the acetabulum was correctly reamed and in whom there was no space between the hip socket and the surface of the acetabulum.

Persistent pain following an arthroplasty: The major part of the pain caused by degenerative joint disease and ankylosis of the hip joint was relieved by arthroplasty in ten of the twelve patients observed for two years. Nearly all patients, however, described muscle soreness and vague pains in the thigh after strenuous exercise. In two patients, there was also persistent pain in the region of the anterior aspect of the hip joint. In both instances, the superior portion of the femoral head was necrotic. The dead bone had not been excised and the head was not properly reamed down to the level of normal cancellous bone. It is possible that pain following arthroplasty originates in the visceral capsule at the junction between living and dead bone. A necrotic femoral head should not be placed in the socket; it is better to ream the necrotic bone down to good bleeding bone, to remove the tip of the trochanter, and to transplant the glutaeus medius muscle insertion distalward at the same time.

Subluxating femoral head: In the process of repair of the joint following an arthroplasty, the hip may lose stability in some patients while it gains in range of motion. Unilaterally in two patients with hip sockets bilaterally, there was a subluxating joint with

FIG. 11-A

FIG. 11-B

FIG. 11-C

Fig. 11-A: Roentgenogram showing degenerative joint disease associated with osteochondromatosis of the hip joint in a man thirty-five years old (Case 5).

Fig. 11-B: Anteroposterior roentgenogram of the hip joint approximately three years following arthroplasty.

Fig. 11-C: Frog-leg lateral roentgenogram of the hip. Note the new articular cortex formed against the convex surface of the socket.

adduction and flexion of the hip beyond 100 degrees. This was observed in: (1) occasional episodes of "popping" of the joint, (2) gait phenomena such as an exaggerated Trendelenburg list or piston mobility in walking without aid, and (3) cinemaroentgenograms of patients "marching in place". The femoral head appeared to slide from the central to the superior portion of the socket. The excursion ranged from slight eccentric movements to marked impingement of the head upon the acetabular rim. These patients had a normal range of active and passive motion, walked without crutches, returned to their former employment, used the joints vigorously in standing and walking, and complained only of moderate aching pains in the thigh. There was no pain in sitting or at bed rest as there had been before the operation. In six patients with a range of flexion of approximately 115 degrees, fluoroscopy showed slight eccentric motion but no subluxation. In four patients with unilateral degenerative joint disease, with a recovery of only 80 to 90 degrees of flexion, there was no eccentric motion and excellent stability. Thus it would seem that the greater the range of motion beyond 90 degrees, the more instability; the lesser the range of flexion, the lesser the external

FIG. 12-A

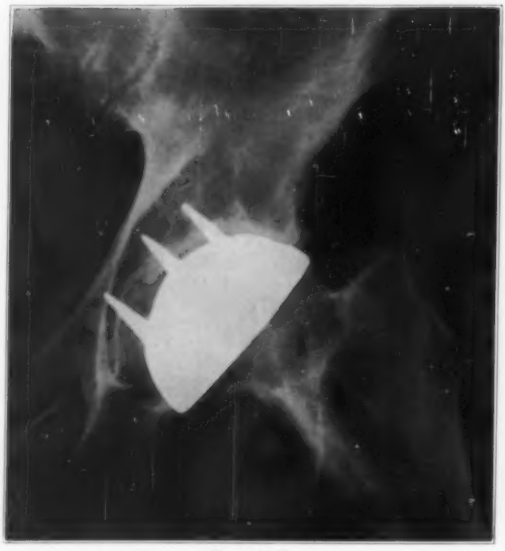


FIG. 12-B

FIG. 12-C

Fig. 12-A: Roentgenogram showing a defect in the femoral head associated with thrombocytopenic anaemia and degenerative joint disease in a forty-year-old man (Case 9).

Fig. 12-B: Anteroposterior roentgenogram of the hip approximately two years following hip-socket arthroplasty.

Fig. 12-C: True lateral roentgenogram of the hip approximately two years after the operation. The notch in the socket overlies the incisura acetabulae.

FIG. 13-A

FIG. 13-B

FIG. 13-C

Fig. 13-A: Roentgenogram showing degenerative joint disease five years after a fracture-dislocation of the hip joint in a man thirty-eight years old (Case 11).
Fig. 13-B: Roentgenogram showing unsuccessful Vitallium-mold arthroplasty, two years after the operation.
Fig. 13-C: Roentgenogram approximately two years after hip-socket arthroplasty. The tip of the trochanter was removed and the tendon of the glutaeus medius muscle was transplanted to the externus tubercle of the femur.

TABLE I-A

TWO-YEAR RESULTS

Case	Age	Diagnosis	No. of Years Following Arthroplasty	Pain after Strenuous Exercise	Range of Flexion (*Degrees*)	Aids
1	68	Malum coxae senilis	3	Slight	120	Cane
2	68	Malum coxae senilis	3	Slight	125	Cane
3	60	Old fracture-dislocation	3	None	115	None
4	38	Old Legg-Perthes disease	3	Slight, if any	80	Cane
5	35	Osteochondromatosis and degenerative joint disease	3	Slight, if any	90	Cane
6	56	Malum coxae senilis	2	Slight, if any	120	None
7	56	Malum coxae senilis	2	Slight, if any	120	None
8	39	Degenerative joint disease	2	Slight, if any	110	Cane
9	40	Degenerative joint disease	2	None	125	None
10	42	Degenerative joint disease	2	None	85	Cane
11	38	Old fracture-dislocation	2	Moderate	110	Cane
12	37	Degenerative joint disease	2	Slight	80	None

rotation and unscrewing of the joint and the greater the stability. Subluxating hip joints following arthroplasty could be caused by one or more of several conditions: muscle weakness, a large or loose-fitting socket, absorption of the femoral head, pre-existing acetabular dysplasia, and hypermobility or an extreme degree of flexibility of the hip. Instability of the hip has also been observed in patients with fascial membrane arthroplasty and other kinds of arthroplasties. The nature of the original joint disease undoubtedly determines the degree of recovery of motion, femoral-head resorption, and eventual stability.

RESULTS

Degenerative Joint Disease

In Tables I-A and I-B are summarized the results in twelve arthroplasties on patients

TABLE I-B

RANGE OF MOTION TWO YEARS AFTER OPERATION

Case No.	Adduction (*Degrees*)	Abduction (*Degrees*)	External Rotation (at 180 Degrees)	Internal Rotation (at 180 Degrees)	External Rotation (at 90 Degrees)	Internal Rotation (at 90 Degrees)	M.G.H. Rating *
1	30	40	30	30	25	25	$A_2E_4F_4$
2	30	40	30	30	25	25	$A_2E_4F_4$
3	30	30	20	20	20	10	$A_2E_2F_4$
4	20	20	20	10	20	10	$A_2E_1F_2$
5	30	20	10	10	10	10	$A_2E_4F_2$
6	40	30	30	20	30	20	$A_2E_4F_4$
7	40	30	30	30	30	30	$A_2E_4F_4$
8	30	30	20	20	20	10	$A_2E_2F_4$
9	30	20	20	10	20	10	$A_2E_1F_2$
10	30	20	30	20	30	20	$A_2E_1F_2$
11	40	20	30	10	10	10	$A_2E_2F_2$
12	40	20	20	20	20	10	$A_2E_2F_4$

* As applied in previous investigations [26]: A = Anatomic,
E = Economic,
F = Function,
1 to 4 = estimate of the results according to the scale of the Massachusetts General Hospital Fracture Service.

TABLE II

COMPLICATIONS AND RE-OPERATIONS

Case No.	Age	Preoperative Diagnosis	Complication	Final Treatment	Follow-up (*Years*)	Flexion (*Degrees*)	Result
1	35	Old fracture-dislocation; extensive cystic degeneration of the femoral head.	Infection	Arthrodesis	2		Good
2	65	Old wedge osteotomy of the ilium for degenerative joint disease.	Infection	Girdlestone resection	2	100	Poor
3	48	Pseudohemophilia, avascular necrosis.	Infection	Girdlestone resection	2	80	Poor
4	67	Osteo-arthritis and rheumatoid arthritis.	Fracture of shoe nail	Revision	2	90	Good
5	39	Rheumatoid arthritis.	Ankylosis	Revision	2	10	Poor

with various forms of degenerative joint disease; these patients were examined between two and three years after the time of the operation. Thirty-one additional patients with more recently performed arthroplasties who have been followed less than two years following operation will be described later when five-year end-result examinations can be presented. In Table II are presented observations on five complicated unsuccessful arthroplasties; the patients were subjected to re-operations. In the ten-year period preceding and including the three-year period of this study, approximately thirty-six Vitallium-mold arthroplasties and forty-five hip-replacement operations were performed in Wadsworth Hospital. It is planned to compare the results obtained in hip-socket arthroplasty with the results from the Vitallium-mold and hip-replacement arthroplasties observed at Wadsworth and with other methods reported in the literature [4, 7, 8, 12, 15, 19, 24, 25]. At the time of writing the patients treated by hip-socket arthroplasty showed early recovery of function and an excellent range of flexion. As in all forms of arthroplasty and any form of surgical treatment, the eventual result depends upon the nature of the disease, the mental attitude of the patient, and the skill of the surgeon [16]. A feature characteristic of early and late results of hip-socket arthroplasty was the free rotation of the joint at 90 degrees of flexion and at 180 degrees of extension. There was no problem of the socket tilting into an unsatisfactory varus or valgus position after the operation.

The best result from hip-socket arthroplasty was in a woman sixty-eight years old who previously was completely disabled with malum coxae senilis bilaterally, associated with osteo-arthritis of the lumbosacral spine. She had pain during the night as well as during the day when she would attempt to walk on crutches. She consumed large quantities of analgesic drugs. The effects of the arthroplasty were immediate relief from pain and return of 60 degrees of flexion after one month, 80 degrees at six months, 90 degrees at nine months, and 120 degrees at twelve months. The results were equally good in most of the patients with malum coxae senilis and in some of those with other forms of degenerative joint disease.

Rheumatoid Arthritis

The immediate postoperative recovery of motion in a patient with Marie-Strümpell arthritis was very little compared with that observed in the patients with malum coxae senilis. Contractures, atrophy, and immobility of the periarticular soft parts and muscles added problems that could not be solved by simply implanting a socket or trimming the articular surfaces. In order to overcome ankylosis associated with severe adduction flexion deformities, the femoral head and neck were excised, the trochanter was reshaped and was

placed in the acetabulum, and the glutaeus medius tendon was transplanted distalward in the lateral aspect of the shaft of the femur. The hips were immobilized in wide abduction for three weeks. While the results even with these modifications of hip-socket arthroplasty were hardly ever good, the need for even a little hip-joint motion in patients with Marie-Strümpell arthritis was so great that only 20 or 30 degrees of motion for a limited period of time was much appreciated by the patient.

Old Fractures of the Acetabulum

Arthroplasty is definitely contra-indicated in fresh fractures but can be recommended for old injuries of the acetabulum. One arthroplasty was performed in a patient with a healed severe central fracture of the acetabulum with intrapelvic protrusion. After three years of function, the result was excellent.

Avascular Necrosis of the Femoral Head

Two arthroplasties were performed in patients with extensive avascular necrosis of the head of the femur. In both instances, the necrotic head was placed in the socket without excision of necrotic bone; failure resulted. In two similar patients seen two years after operation and in others operated upon recently, the head has been reamed down to normal bone tissue. The results in these patients appear to be quite good, and it is assumed that the reason is that the articular cortex was carefully erased down to normal bleeding cancellous bone (Figs. 9 through 13).

REPAIR AND ADAPTATION OF THE BONE TISSUE SURROUNDING THE HIP SOCKET

The socket was found to be relatively immobile in the bone tissue of the pelvis in five patients subjected to re-operation. The metal, however, was enveloped in dense fibrous tissue on all sides, except the polished concave inside surface against the moving femoral head. The fibrous envelope was less than a millimeter in thickness and permitted the mold to vibrate and to move infinitely small fractions of an inch in any direction in a manner similar to the movement that might be expected between the seams of any two semirigid structures in the body.

Remodeling of the femoral head: Pressure of weight-bearing apparently converts the fibrocartilage to something very like hyaline cartilage and converts the subchondral cancellous bone to compact bone. The differentiation of hyaline cartilage in the fibrous covering of the head of the femur barely begins at eighteen months. In the process the raw surface of cancellous bone is absorbed and remodeled and the size of the femoral head becomes one-eighth to three-sixteenths of an inch less in diameter than it was as seen in the roentgenogram made immediately after the operation. The fibrocartilage cells show amitotic division into paired chondrocytes. Thus the small femoral head seen in roentgenograms of patients with successful arthroplasties is the product of concurrent proliferation of fibrocartilage from endosteum and remodeling of cancellous bone to form a new articular cortex and hyaline-like cartilage.

Remodeling of the acetabulum and inward drift of the socket: Serial roentgenograms show that, after two years, approximately one-eighth of an inch of the cancellous bone of the pelvis is absorbed and remodeled beneath the fibrous tissue and fibrocartilage formed upon the convex surface of the acetabulum. In this process the socket migrates a corresponding distance of one-eighth of an inch inward through the substance of the innominate bone. If the tips of the shoe nails perforate the pelvis, a protective cap of new bone forms over the fibrous tissue surrounding the end of each one. The distance the socket can drift, however, is limited by the acetabular rim, the platform, and the wall of new compact bone behind it. Dense fibrous tissue and very little fibrocartilage form between the metal and the bone on the pelvic side of the socket. The metal thus eventually becomes encapsuled on all sides by a two-layered envelope of fibrous tissue and compact bone.

SUMMARY

1. Hip-socket arthroplasty is a procedure developed from a study of the biomechanics of the hip joint, histophysiological observations of joint repair, and clinical experience with a Vitallium socket attached to the pelvis.

2. Special surgical instruments have been designed for implanting the socket through a posterolateral approach. The hip socket is a self-sustained lining for the acetabulum and is stable enough to allow motion immediately after the operation. The socket is open at the inferior margin to permit regeneration of a structure resembling the ligamentum teres and mucin-forming synovial cells inside the joint. It encloses only half of the head of the femur and thereby permits a wide range of motion.

3. The morphological and chemical structure of a pseudarthrosis and a functioning arthroplasty are identical and the two conditions involve the same connective-tissue-cell processes. The first covering of the articular surface is granulation tissue, fibrinoid, and fibrous tissue. After six months differentiation occurs to form fibrocartilage and after eighteen months new cartilage, resembling hyaline cartilage, appears in the deep layers in contact with cancellous bone. The joint surface formed from an arthroplasty after years of function resembles articular cartilage. Although it is not true articular cartilage, it becomes increasingly like articular cartilage after a period of years of weight-bearing and after remodeling of the underlying spongiosa to produce a new articular cortex of compact bone.

4. Forty-eight hip-socket arthroplasties have been performed in the years between 1953 and the present time. Five arthroplasties with complications were subjected to revision, arthrodesis, or resection operations six to eighteen months after the arthroplasty. Results in the first twelve hip-socket arthroplasties (including two bilateral) examined between two and three years after the operation were regarded as *fair* in one, *good* in one, and *excellent* in ten. The patients had less pain than before the operation, had an increase of range of motion, and had a stable joint. Compared with other surgical methods, there was a remarkably free range of rotation combined with flexion. A theoretical explanation is that hip-socket arthroplasty permitted derotation or unscrewing of the head of the femur during the swing phase of the joint motion. Further investigations and long-term end-result studies are in progress and will be reported later.

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The Self-Locking Metal Hip Prosthesis

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From The Moore Clinic, Columbia

In 1940, in collaboration with Dr. Harold Bohlman of Baltimore, the author inserted the first Vitallium prosthesis to replace the upper portion of a femur. This was done after the removal of a questionably malignant tumor of the upper end of the femur in the intertrochanteric region [1]. The operation was successful. The patient gained approximately 75 per cent of normal function of the hip and lived for about two years before he died of a heart attack.

Some years later, the Judet brothers of Paris introduced a new stem type of endoprosthesis to replace the femoral head. This appeared to give satisfactory results, and variations of their model began to appear. The author was not impressed with the stem type of prosthesis and continued to search for an appliance which would promise better distribution and support of the normal stress load.

In 1950, with the assistance of the Professor of Engineering at the University of South Carolina and the Chief Engineer of the Austenal Laboratories, an intramedullary type of prosthesis was developed. A straight prosthesis with a solid stem was used at first and was applied through the anterior approach. This operation was found to be very difficult, and dislocation of the hip occurred in one or two patients following surgery. The prosthesis was modified in order to obtain the proper angle of the femoral neck on the shaft of the prosthesis, and the stem was fenestrated in order to lock the prosthesis in position and to allow better blood supply through the upper end of the femoral shaft. A suitable type of rasp was designed with which to seat the prosthesis correctly. A special posterior approach was developed by which the prosthesis could be inserted more easily than by the anterior approach. Through repetition of the operation, the incision was gradually shifted more posteriorly until eventually it became known as "the southern exposure" (Figs. 1-A and 1-B).

The approach is low on the buttocks, the lower glutaeus maximus fibers are separated, and none of the abductor muscles attached to the greater trochanter are divided (Figs. 2-A through 2-D). This preserves the strength and integrity of the hip, it obviates a postoperative abductor lurch and limp, and enables the patient to be up and about within a few days after surgery. The operation can be completed in twenty to thirty minutes, although the time scheduled is usually about forty-five minutes. There is very little blood loss and usually no shock. Precision is of utmost importance. Candidates for this surgery should be carefully selected. Operative risk and the degree of future function should be calculated. Accurate measurements and complete operative plans should always be made prior to surgery. At the time of operation, meticulous care should be taken in order to obtain a perfect fit of the prosthesis, with anatomical reconstruction as accurate as possible. End results are in direct proportion to the surgeon's preoperative planning and technical precision [2].

In the past six years this method has been used in a wide variety of cases; 159 operations have been performed on 153 patients. The results have ranged from excellent to poor, but with increasing experience we are convinced that a high percentage of satisfactory results can be obtained by this method. In fresh fractures of the neck of the femur there is always the question whether a prosthesis should be used. For years I have treated fractures of the femoral neck with multiple nailing, using the Moore adjustable nail [3]. For years I have stressed the importance of early perfect reduction, perfect fixation, and perfect postoperative protection until union has occurred. With this program,

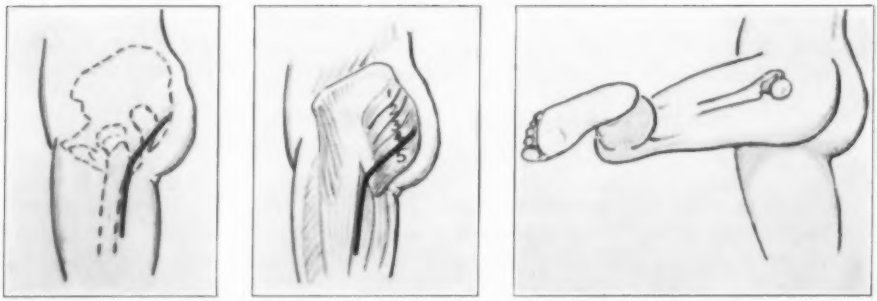

FIG. 1-A

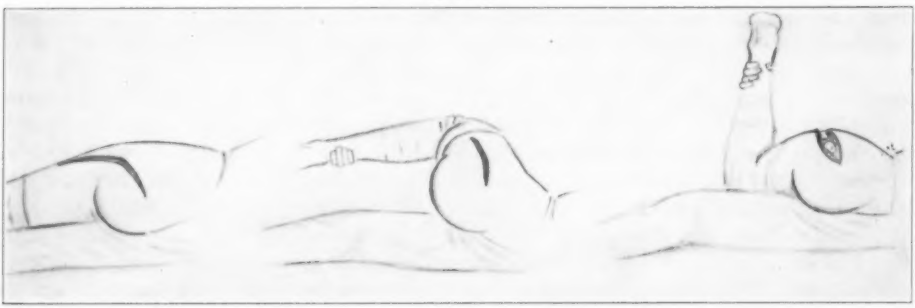

FIG. 1-B

Figs. 1-A and 1-B: The patient lies on his unaffected side. The incision is low on the buttocks and behind the greater trochanter. The thigh is flexed and internally rotated with the toe pointed toward the ceiling in order to dislocate the femoral head ("the southern exposure").

many excellent end results can be obtained. The poorer the technique, the poorer will be the end result. High, subcapital femoral-neck fractures and Pauwel type 3 fractures are the most difficult to reduce, but they will heal satisfactorily when treated by correct reduction, nailing, and well conceived postoperative protection. Fractures partially reduced may unite, but almost invariably there will be more or less aseptic necrosis of the femoral head. Traumatic arthritic changes in the hip joint take place in proportion to the degree of trauma and the skill with which the operation has been performed. Disturbance of the blood supply must be kept at a minimum.

When fractures of the femoral neck can be treated with satisfactory results by a method which preserves the natural head of the femur, there is no reason for the insertion of a prosthesis. When a better result can be obtained with artificial replacement of the head of the femur, there is every justification for the use of a prosthesis.

I have been orthopaedic surgeon at the Columbia State Hospital for the mentally ill for the past thirty years. There are approximately 7,000 beds in this institution, and a fairly large number of hip fractures occur in our patients. Many of these patients are aged, they are in poor physical condition for surgery, and they will not survive a long period of bed recumbency. Most of them are unable to cooperate with a program of postoperative protection following hip nailing. Results of hip nailing in this type of patient are poor. Patients who become bedridden require increased nursing and attendant care, and are, therefore a greater financial burden to the State. The insertion of a prosthesis can be done with no more risk to the patient than a hip-nailing operation, and frequently the risk and the shock are not so great. These factors indicate the value of the use of a prosthesis in treatment of fresh femoral-neck fractures in patients who are confined to a mental institution. Frequently the patients are up and about within a few days after surgery, and often no special nursing or attendant care is necessary.

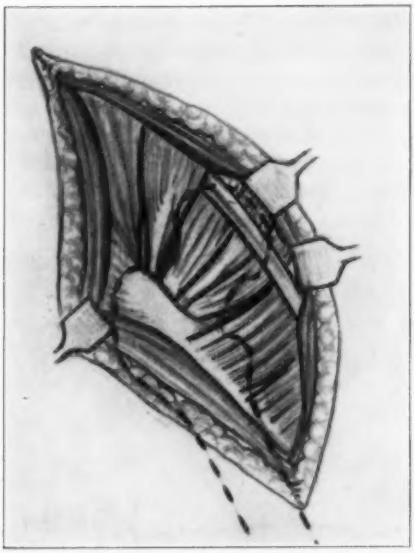

FIG. 2-A

FIG. 2-B

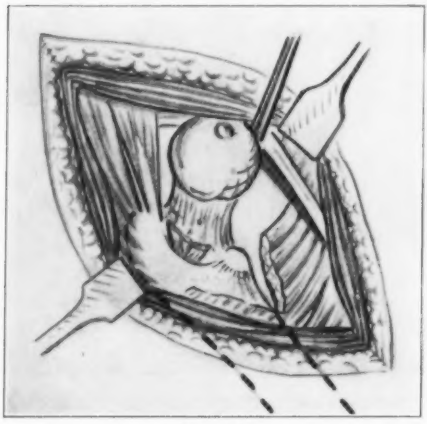

FIG. 2-C

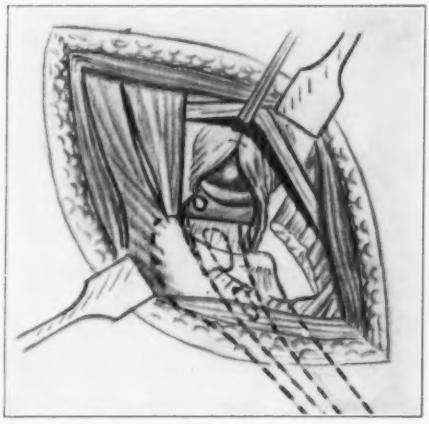

FIG. 2-D

Figs. 2-A through 2-D: The sciatic nerve is retracted and the branch to the posterior aspect of the hip capsule is divided. The attachment of the short extensor rotators, part of the quadriceps femoris, and possibly the piriformis are divided. The distal attachment of the hip-joint capsule is removed and the capsule is incised to the acetabulum in order to allow the femoral head to be removed. The edges of the wound fall back together and very little suture is required.

A prosthesis may be indicated in other types of fractures. In patients with Parkinson's disease, hemiplegia, or some other infirmity because of which they are unable to use crutches and cannot adequately protect themselves following a hip-nailing operation, the use of a prosthesis seems to be justifiable. The patient's age, weight, physical and mental fitness, social and economic status, domestic facilities, and psychological attitude are all factors to be considered when deciding whether or not a prosthesis should be used. It is not possible to lay down specific rules. Each patient is an individual problem. One of the best ways to arrive at a decision is to consider what the patient will be able to do and what can be expected if a prosthesis is not used. When this is compared with what may be expected from the insertion of a prosthesis, the decision can be readily made.

TECHNIQUE OF OPERATION

Accurate measurements of the hip and the extremity should be made prior to the operation, and exact operative procedure should be planned so that the head and neck of the femur may be replaced as perfectly as possible. If the neck of the femur is lengthened by a prosthesis which is too large, the hip-joint capsule may be stretched and there will be residual pain. If the size of the head of the prosthesis is too small, there will be degenerative changes in the acetabulum with consequent "wandering acetabulum", traumatic arthritis of the hip, or arthrokatadysis. In order to distribute the stress evenly

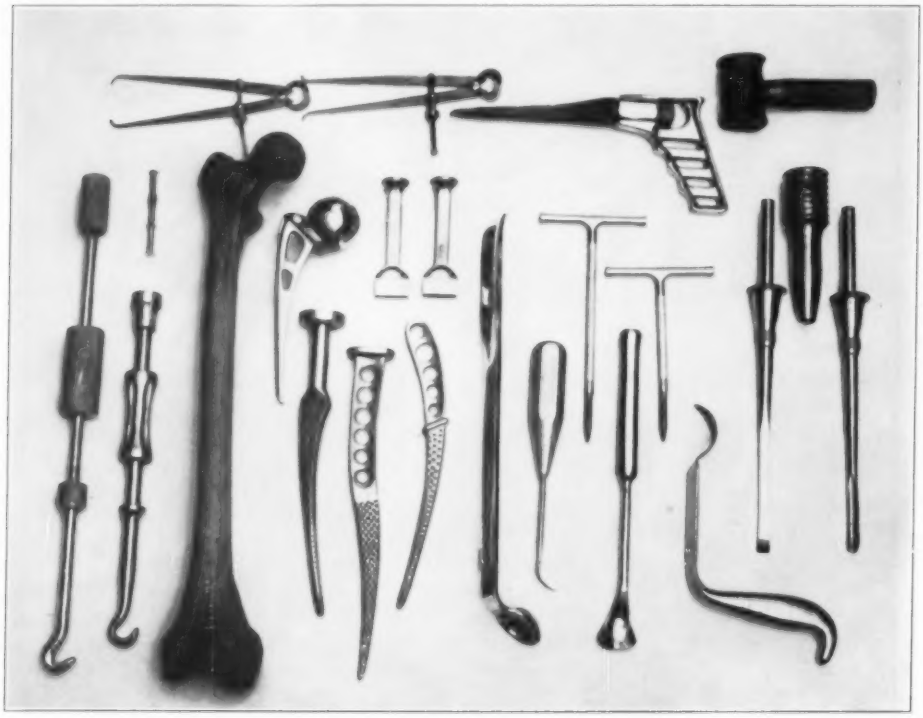

FIG. 3

Special instruments designed for use in inserting the prosthesis.

Top row: outside and inside calipers for measuring the head of the femur and the acetabulum; bone saw and heavy bronze mallet.

Below, at the left of the femur: driver extractors and a small measuring rod, marked to measure one inch, one and one-half inches, one and five-eighths inches, one and three-fourths inches, two inches, and two and one-eighth inches. With this rod strapped to the patient's thigh and with the use of calipers, exact dimensions can be calculated for a prosthesis of perfect fit. The purpose of the instruments at the right of the femur is obvious.

it is important that the head of the prosthesis fit perfectly. At the time of surgery the five different sizes of the prosthesis should be at hand.

The patient lies on his side with the injured hip uppermost; the thigh on the injured side is flexed to approximately 45 degrees. The incision is begun low on the buttocks, about two inches distal to and toward the outer side of the posterior inferior spine of the ilium. It courses downward and outward just beneath the greater trochanter and extends along the outer side of the thigh about four inches below the greater trochanter. The use of the posterior incision avoids pressure or tension necrosis which may occur when the incision is made directly over the greater trochanter. The fascia lata just be-

neath the greater trochanter is incised, and this incision is continued upward, dividing the aponeurotic insertion of the glutaeus maximus. It is easy, then, manually to separate the lower fibers of the glutaeus maximus upward to the point where the superior gluteal vessels are encountered. The glutaeus maximus fibers which have been separated are about one and a half inches above the lower border of this muscle. This exposure is made with practically no bleeding; wound towels are applied and the patient's thigh is flexed further, toward a right angle; the upper fibers of the glutaeus maximus are easily held

FIG. 4

Prosthesis models used from 1939 to 1951. At the left is a femur with an early type of prosthesis which was inserted in 1939 by Moore and Bohlman [1]. The specimen was removed at autopsy, two and a half years after insertion. The straight-stem prosthesis was used in a few early cases. The prosthesis with oval-shaped fenestrations was used until recently. The openings were slightly enlarged and flattened at their upper margins to improve stress-bearing surfaces.

above the greater trochanter with a retractor. The sciatic nerve lies fully exposed in the lower part of the wound. It is retracted medially; and, as it is dissected upward, the small branch of this nerve extending to the external rotators of the hip and to the posterior capsule of the hip joint is easily identified and resected. Resection of this nerve is thought to be of benefit in relieving postoperative pain. In some patients the distal insertion of the lower fibers of the glutaeus maximus may have to be partially divided for ample exposure. The fatty tissue behind the lower portion of the capsule of the hip joint in the intertrochanteric region is removed. The insertions of the short external rotators, the gemelli, and the obturator internus are divided, and as these muscles are retracted the posterior aspect of the hip capsule is exposed. Occasionally it may be necessary to divide the inser-

TABLE I

STATISTICAL TABLE OF FIFTY-FIVE PATIENTS WITH FOLLOW-UP RESULTS OF TWO YEARS OR MORE *

	Patient	Result	Age	Pain	Diagnosis	Walk		Work	Motion (*Per cent*)	Operation	Prosthesis Size (*Inches*)
						Limp	Support				
1.	Mrs. T.P.	Excellent	74	None	Acute fracture; Parkinson's disease	Moderate	Cane	Housewife	100	10-30-53	1⅞
2.	Mrs. A.F.K.	Excellent	72	None	Acute fracture	Slight	Cane	Housewife	100	7-7-54	1⅞
3.	Mrs. G.R.	Excellent	42	None	Old fracture; aseptic necrosis	Slight	None	Housewife	100	9-25-53	2
4.	Mrs. L.K.P.	Excellent	61	None	Acute fracture	Slight	None	Mill worker	100	6-20-53	1⅞
5.	Mr. F.T.	Good	62	Slight	Old fracture-dislocation; arthritis	Moderate	Cane	Farmer	100	6-12-53	2
6.	Mr. E.W.	Excellent	40	None	Arthritis; old osteochondritis dissecans with aseptic necrosis	None	None	Farmer	100	5-8-53	2⅛
7.	Mrs. H.Z.	Excellent	83	Slight	Acute fracture	None	None	Housewife	100	8-4-53	1⅞
8.	Mr. D.M.	Fair	17	Slight	Old septic arthritis	Severe	Crutch	Student	70	7-8-52	2
9.	Mr. J.R.W.	Fair	63	Slight	Degenerative arthritis	Moderate	Crutch	Farmer	100	5-3-54	2⅛
10.	Mrs. J.R.K.	Excellent	55	None	Fracture, non-union	Slight	Cane	Housewife	100	5-27-52	1⅞
11.	Mrs. W.H.C.	Excellent	39	None	Old fracture, non-union	None	None	Office work	100	7-16-53	1¾
12.	Mrs. L.S.	Excellent	75	None	Acute fracture	None	None	Housewife	100	12-14-51	1⅞
13.	Mr. L.C.	Good	89	None	Acute fracture	Severe	Walker	Retired	75	12-18-53	2⅛
14.	Mrs. C.M.	Good	70	Slight	Acute fracture	Slight	Cane	Housewife	85	12-24-52	1⅞
15.	Mr. H. McC	Excellent	29	None	Gun shot; arthritis	Slight	Cane	Farmer	75	3-5-54	2
16.	Dr. S.R.G.	Good	46	None	Old fracture; non-union	Moderate	Cane or crutch	Physician	60	3-20-51	2⅛
17.	Miss E.T.	Good	52	Slight	Old fracture-dislocation; aseptic necrosis; arthritis	Slight	Cane	Secretary	100	2-24-53	1¾
18.	Mrs. D.S.	Excellent	50	None	Old fracture with aseptic necrosis	Slight	None	Housewife	100	7-1-52	1⅞
19.	Mrs. J.F.	Fair	50	Slight	Arthritis	Moderate	None	Housewife	60	5-7-52	1⅞
20.	H.M.	Poor	22	Slight	Marie-Strümpell arthritis	Moderate	Crutch	Student	33⅓	10-12-51	1⅞ left

20-A.	H.M.	Poor	22	Slight	Marie-Strümpell arthritis	Moderate	Crutch	Student	33⅓	10-26-51	1⅞ right
21.	Mrs. A.W.	Poor	52	Slight	Old fracture with non-union	Moderate	Cane	Beautician	75	7-25-51	1¾
22.	Mr. T.C.A.	Poor	47	Severe	Marie-Strümpell arthritis	Severe	Wheel chair		33⅓	5-11-54	2 right
22-A.	Mr. T.C.A.	Poor	47	Severe	Marie-Strümpell arthritis	Severe	Wheel chair		15	1-25-55	2 left
23.	Mr. L.L.	Good	31	None	Generalized traumatic arthritis; Naden-Reith prosthesis removed	Slight	Cane	Office work	100	3-18-55	1¾
24.	Mr. J.D.L.	Fair	44	Mild	Traumatic arthritis	Moderate	Crutch	Watchmaker	50	4-6-55	2⅛
25.	Mrs. E.S.	Fair	66	Slight	Acute fracture	Slight	Crutch	Housewife	100	12-30-51	1⅞
26.	Mrs. G.P.	Good	50	Slight	Degenerative arthritis; cup was removed	Moderate	Cane	Housewife	100	10-7-54	1⅞
27.	Mr. L.C.	Excellent	59	Slight	Arthritis, bilateral; to return for operation on other hip	Moderate	Crutch	Retired	75	10-29-55	2⅛
28.	Mrs. M.H.	Good	27	None	Old infectious arthritis	Slight	Cane	Housewife	75	8-17-54	1⅞
29.	Mrs. G.P.	Excellent	70	None	Fracture, non-union	Slight	None	Retired	100	6-1-54	1¾
30.	Mr. F.W.G.	Good	64	Slight	Arthritis	Moderate	Cane	Retired	75	10-20-54	2 left
30-A.	Mr. F.W.G.	Good	64	Slight	Arthritis	Moderate	Cane	Retired	65	11-9-54	2 right
31.	Mrs. L.M.	Excellent	51	None	Arthritis	Slight	None	Mill worker	100	7-27-54	1⅞
32.	Mrs. E.P.	Fair	72	Slight	Bilateral fracture, non-union	Moderate	Crutches	None	100	11-5-54	1¾
33.	Mrs. F.McK	Good	69	Slight	Old fracture with aseptic necrosis	Moderate	Cane	Retired	100	11-23-54	1¾
34.	Mrs. I.O.	Fair	43	Slight	Arthritis; old congenital dysplasia, bilateral	Moderate	Crutch	None	100	1-4-55	1⅞
35.	Mrs. E.D.	Excellent	56	None	Fracture with non-union	None	None	Housewife	100	11-17-53	1¾
36.	Mrs. C.G.	Good	62	Slight	Fracture with non-union; Parkinson's disease	Moderate	Cane	None	100	5-19-53	1⅞
37.	Mr. L.H.	Good	72	Slight	Fracture with non-union	Slight	Crutch	None	75	2-24-53	1⅞

TABLE I *(continued)*

	Patient	Result	Age	Pain	Diagnosis	Walk		Work	Motion (*Per cent*)	Operation	Prosthesis Size (*Inches*)
						Limp	Support				
38.	Mrs. J.R.	Fair	53	Slight	Old slipped epiphysis with arthritis	Slight	Crutch	None	50	5–18–51	1⅞
39.	Mrs. A.E.	Good	77	None	Old fracture with non-union	Moderate	None	Retired	75	11–21–52	1¾ left
39-A.	Mrs. A.E.	Good	77	None	Acute fracture	Moderate	None	Retired	75	6–20–53	1¾ right
40.	Miss V.McC	Good	18	Slight	Rheumatoid arthritis; cup arthroplasty	Moderate	Cane	Secretary	20	4–11–51	1⅝ left
40-A.	Miss V. McC	Good	18	Slight	Rheumatoid arthritis; cup arthroplasty	Moderate	Cane	Secretary	10	3–7–52	1⅝ right
41.	Mrs. B.K.	Excellent	76	None	Fracture with non-union	Slight	Cane	Housewife	100	1–15–54	1⅞
42.	Mr. W.M.	Fair	16	Moderate	Slipped epiphysis	Moderate	Crutch	Light work	65	8–7–53	2
43.	Mrs. A.A.	Good	62	Slight	Fracture with non-union	Slight	Cane	Housewife	100	2–2–54	1⅞
44.	Mrs. D.C.	Good	50	Moderate	Old fracture; aseptic necrosis	Slight	Cane	Housewife	90	4–25–52	1¾
45.	Mr. B.T.	Fair	16	Moderate	Traumatic arthritis	Slight	Crutch	Light work	75	3–12–51	2
46.	Mr. C.C.	Failure	46	Moderate	Old osteomyelitis	Severe	Crutch	Light work	60	2–8–52	1⅞
47.	Mr. L.S.	Good	15	Mild	Slipped epiphysis, bilateral	Moderate	Cane	Light work	75	10–6–53	1⅞
47-A.	Mr. L.S.	Good	15	Mild	Slipped epiphysis, bilateral	Moderate	Cane	Light work	75	10–29–53	1⅞
48.	Mrs. G.H.	Good	63	Mild	Fracture, non-union	Slight	Cane	Light work	100	4–3–53	1¾
49.	Mr. H.H.	Good	66	Mild	Fracture, aseptic necrosis	Slight	Cane	Light work	100	4–28–52	1⅞
50.	Mrs. S.P.	Excellent	65	None	Fracture with non-union	Slight	None	Housewife	100	5–14–53	1¾
51.	Mrs. E.C.	Good	81	None	Acute fracture	Slight	Cane	Retired	100	3–10–54	1¾
52.	Mr. D.T.	Excellent	62	None	Acute fracture	None	None	Farmer	100	4–18–52	1⅞
53.	Mrs. C.B.	Good	54	Moderate	Old fracture with non-union	Slight	Cane	Light work	75	1–17–51	1⅞
54.	Mrs. H.K.	Good	71	Moderate	Old fracture with aseptic necrosis	Slight	Cane	Light work	100	4–7–52	1⅞
55.	Mr. G.A.	Excellent	21	None	Slipped epiphysis	Slight	None	Light work	100	10–12–54	2

* In this table the length of follow-up in each case is the time between the date of operation and October 19, 1956, when this study was completed.

tion of the piriformis or the upper third of the insertion of the quadratus femoris. The hip capsule is incised in line with the long axis of the femoral neck upward to the acetabular margin. The distal insertion of the capsule into the posterior portion of the femoral neck is separated from its attachment until a full view of the lower posterior portion of the neck is obtained. The distal capsular attachment is stripped downward to expose completely the lower and under surface of the femoral neck. The lesser trochanter, an important landmark, can now be readily identified. The only blood vessel that may need to be ligated is the posterior circumflex artery; usually ligation of this vessel is not necessary. There should be practically no bleeding. Dislocation of the femoral head from the socket is usually accomplished with little difficulty. The thigh is flexed to a full right angle and adducted, and the leg is turned into internal rotation at a right angle, with the knee flexed to 90 degrees. In this position the foot of the patient points directly upward toward the ceiling. The surgeon should be careful not to apply excessive force in this manipulation, for it is possible to fracture the shaft in attempting to dislocate the femoral head. Usually a long screw with a special T type handle is placed in the femoral head in order to pull and lever the head out of the socket, or a small skid can be used for this purpose. The neck of the femur is cut with a saw one-half to three-quarters of an inch above the lesser trochanter. This cut must be made in exactly the right plane to ensure the perfect fit of the prosthesis and to incline it forward in order to preserve the normal anteversion of approximately 20 degrees. In instances when it is difficult to displace the femoral head from the acetabulum, the neck of the femur may be divided and the head subsequently removed. The ligamentum teres, if present, is divided so that no stump remains, and the acetabulum is carefully inspected. Usually I do not remove any of the acetabular cartilage or attempt to deepen the socket. In exceptional cases, osteophytes or overgrown bone about the acetabular margin may be removed. Extreme care must be exercised in fitting the prosthesis. The shaft of the femur is not hollowed out, for this would result in a loose fit, but special chisels and a special rasp are used to remove bone from the shaft, a little at a time, so that finally, when the stem of the prosthesis is driven into place, the fit is accurate and tight. Before the final seating of the prosthesis, bits of cancellous bone removed from the femoral neck and the upper end of the femoral shaft are placed in the fenestrations of the prosthesis. These pieces of cancellous bone are actual bone grafts; they grow and become increasingly dense, locking the prosthesis in place and adding strength to withstand the stress of weight-bearing. Accurate measurements with calipers are made before deciding on the size of the head of the prosthesis to be used, and always the head is placed in the acetabulum for a trial fit before the stem is inserted into the shaft of the femur. Finally, the metallic head is placed in the acetabulum. This should be done without too much force, for too tight a fit will stretch the hip capsule and cause pain; the femoral shaft may even be broken if a fit approximating the natural cannot be obtained. In order to relax the quadriceps femoris and to relieve tension in the hip, the knee joint is extended before applying the traction necessary to replace the femoral head. The femoral head is not replaced by manipulating the extremity, but rather it is pulled downward over the acetabulum and the surgeon gently forces it into the acetabulum. The head of the prosthesis is guided into place by manipulating the extremity from the position of internal rotation into the neutral and anatomical position, and the thigh is brought down from the flexed position into complete extension. In this position the muscles and the capsule of the hip joint fall back together, and only a few deep sutures are necessary to close the wound. The skin is closed loosely with interrupted silk sutures. As the patient lies in bed with the limb extended and externally rotated, the tissues are brought closer together and there is no danger of dislocation of the prosthesis which might occur when an anterior incision is used. With this procedure, we have not had a single case of dislocation of the prosthesis.

It is surprising how often the large size (two inches or two and one-eighth inches)

TABLE II

COMPLICATIONS IN 159 OPERATIONS

In the first six patients, the early straight-stem prosthesis was used, inserted by the anterior approach.		
Dislocations		2
Fracture of the rim of the acetabulum		1
In the subsequent 153 patients, the present prosthesis was used with the improved operative technique		
Operative deaths:		3
Surgical shock	1	
Cardiac arrest	1	
Pneumonia, postoperatively	1	
Wounds infections, superficial		3
Wound infections, severe		1
Old osteomyelitis with recurrent infection two years after surgery; prosthesis removed		1
Prosthesis temporarily loosened in shaft (One was an early model short-stem prosthesis. All relieved by cessation of weight-bearing.)		3
Patients with satisfactory result but with unexplainable pain		2

prosthesis can be used. The prosthetic head size commonly used is one and seven-eighths inches (Tables I and V).

By stripping the muscle attachment from the upper end of the femoral shaft when necessary, this exposure can be used satisfactorily for almost all operations about the hip joint. Following surgery the patient is allowed to move about, with caution, in bed. No external support or traction is necessary. Within a few days he may be up and about on crutches. He may leave the hospital approximately ten days after surgery. Weight-bearing is restricted during the first six months and gradually increased as roentgenograms reveal increasing bone density about the prosthesis. The patient returns for a careful check-up study and a roentgenographic examination every two months for a year following the operation. I insist on six-month or yearly follow-up examinations of all of our patients; they are cautioned that they should carry a cane and be careful in the use of the hip the balance of their lives.

RESULTS

A total of 159 operations have been performed. A statistical study of end results two or more years after operation is reported in Table I.

The results have been proportional to the judgment which was used in selecting the patients and to the operative technique and follow-up care. During two of the early

TABLE III

RESULTS IN FIFTY-FOUR SOUTH CAROLINA STATE HOSPITAL PATIENTS ALL WITH FRACTURE OF THE FEMORAL NECK

Operative deaths:		2
Surgical shock	1	
Pneumonia one week after surgery	1	
Died later:		9
Senile changes; cardiovascular disease		
Walking, no complaint		30
Walking, with complaint of pain		1
Wheel chair		4
Dismissed from hospital in good mental and physical condition		8
Wound infection, superficial		2
Wound infection, severe		1

FIG. 5

Typical high capsular fracture in a mentally ill patient seventy-two years old. The patient was up and about a few days after the operation. No nursing care was necessary. Note the normal outline of the upper end of the femur; there was no shortening. This is the latest type of prosthesis, the proximal fenestrations flattened to sustain weight-bearing stress. The upper surfaces of the fenestrations are flattened, not oval-shaped as formerly, for the same purpose.

operations dislocation occurred when the patient's hip was in the adducted position. This was due to the straight type of prosthesis which was used at that time and to the fact that in the anterior approach to the hip the capsule of the hip joint was detached from the acetabular rim. No dislocation occurred with the present technique. No fracture of the femoral shaft occurred during operation. In the early cases, the patient's extremity was placed in traction and abduction following surgery or the thighs were held apart by means of a special brace. All this has been obviated by the low posterior approach. With the present approach I do not believe it would be possible to dislocate the hip without anaesthesia.

In some of the early patients when the capsule of the hip joint was divided at its acetabular attachment, excessive new-bone formation subsequently developed which limited abduction and produced pain by the pinching of the trochanteric region against this roughened acetabular rim. With the low posterior approach to the hip joint, the acetabular margin is never disturbed. The joint capsule is incised in line with the long axis of the neck of the femur, and the capsule is detached from its distal insertion in the intertrochanteric region. Two of the early operations resulted in complete failure. One patient died of cardiac arrest on the operating table. Several patients died at varying times after the operation, but this mortality rate was no higher than that in similar surgery. There have been three superficial infections but no deep infected wounds. It has been necessary only once to remove the prosthesis. In this instance, the patient had had osteomyelitis of the hip, and the prosthesis was used with mental reservation. The wound healed *per primam*, but two years after surgery infection developed which was considered a

TABLE IV

DIAGNOSIS

Acute fracture of the femoral neck	11
Old fracture with non-union	13
Old fracture with aseptic necrosis	5
Osteo-arthritis	5
Old slipped epiphysis with osteo-arthritis	4
Old traumatic dislocation, osteo-arthritis, and aseptic necrosis	3
Traumatic arthritis	3
Degenerative arthritis	1
Old congenital dysplasia with osteo-arthritis	1
Osteochondritis dissecans with traumatic arthritis	1
Gunshot wound with arthritis	1
Rheumatoid arthritis (cup was removed)	1
Degenerative arthritis (cup was removed)	1
Marie-Strümpell arthritis	2
Old septic arthritis	2
Old osteomyelitis	1
Total	55

flare-up of the osteomyelitis. There have been no cases of arthrokatadysis and no instances in which the prosthesis migrated downward into the femoral shaft. In three patients there appeared to be some motion of the prosthetic stem in the medullary canal, but this was relieved by cessation of weight-bearing and the use of crutches.

In one patient a short-stem prosthesis was used. Definite motion of the stem in the shaft developed; this demonstrated the necessity of a long stem. An audible click could be heard and the patient complained of pain. The condition was controlled by the use of crutches or a cane for support. With increasing strain of weight-bearing there was growing discomfort in the hip, and when weight-bearing was limited the pain was relieved. Two patients complained of pain for which no reason was found. Both of these patients were highly nervous, emotionally unstable women. I reoperated on the hip of one of them and dislocated the head of the prosthesis from the acetabulum in an effort to determine the reason for her pain. No pathological condition was found. Following surgery she said that she was immediately relieved of the pain. She gained in weight and in appearance, but

FIG. 6

Fig. 6: Roentgenogram of a femur which was removed from a patient who died a year and a half after surgery. It shows clearly the bone reaction about the prosthesis in areas where stress is applied. There is increased density under the collar, along the calcar femorale, in the fenestrations (especially their upper borders), along the outer aspect of the lower half of the stem, and under and about the tip of the stem. Microscopic examination of sections cut from this specimen clearly show this bone reaction.

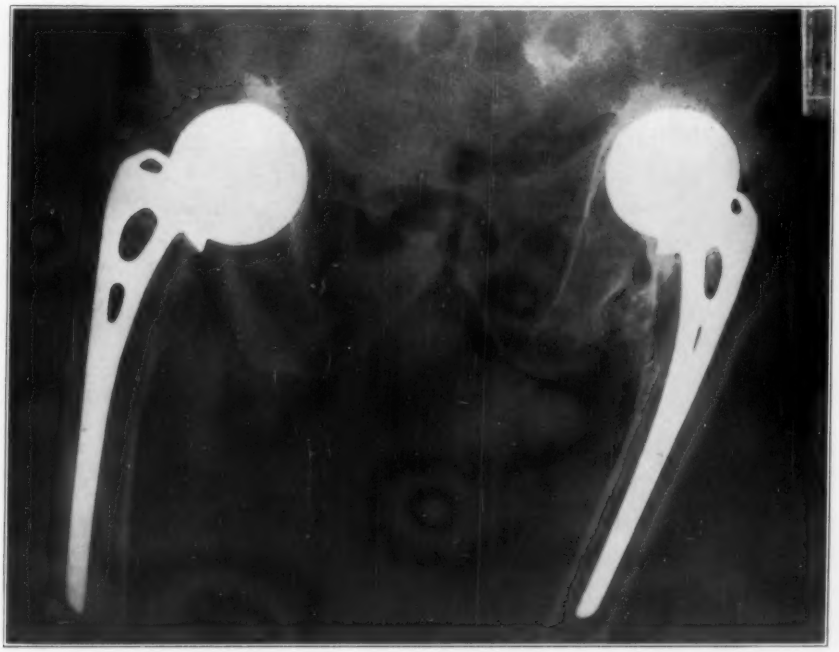

FIG. 7

Patient T.C.A. The diagnosis was advanced Marie-Strümpell arthritis of the spine and hips. The right hip was operated upon May 11, 1954, by Dr. J. S. Barr, of Boston, Massachusetts, who also performed osteotomy of the spine. The patient's left hip was operated upon January 25, 1955, by the author. There are six patients with bilateral hip prostheses in the series.

after a few weeks the pain recurred, and when she was last examined, she continued to complain of discomfort. In no patient has there been evidence of infection, corrosion, or any irritative or malignant change caused by the contact of Vitallium with bone (Table II).

Most of the results are satisfactory, some are excellent. I am confident that they have been more successful than could be expected from any other reconstructive or arthroplastic procedure. With careful control, the prosthesis may give satisfactory service throughout a patient's lifetime. In general, the operation is more suitable for older patients than for young ones. Years of experience will be necessary before positive statements can be made.

STATISTICAL SUMMARY OF TWO YEARS' OR MORE FOLLOW-UP

In the past six years we have fitted 153 patients with the Moore prosthesis. Six of these patients have been operated upon bilaterally. There was a husband and wife in the series. In one patient a cup was allowed to remain in one side and the prosthesis was inserted in the other. In several instances a cup or other type of prosthesis was removed and a Moore prosthesis inserted.

Of the 153 patients, fifty-four were patients in the Columbia State Hospital. All of these patients had fractures of the femoral neck. The patients were in varying stages of mental illness, and in many instances their general health was poor. Control of these patients was impossible. Surgery was planned in an effort to minimize nursing and attendant care. The results have been generally satisfactory, and economically, as well as in increased comfort to the patient, the procedure has been justified. The problem is still under study (Table III).

FIG. 8

FIG. 9

Fig. 8: Patient Mrs. W.H.C. Follow-up examination three and a half years after operation showed an excellent result with practically normal function. Roentgenograms showed anatomical reconstruction and increased bone density where the stress load was carried. These changes are seen in the roentgenogram under the collar and tip of the prosthesis, about the stem, along the calcar femorale, and in the upper weight-bearing portions of the fenestrations. This is in accordance with Wolff's law. The prosthesis literally becomes part of the living bone.

Fig. 9: Dried specimen. This femur was removed at autopsy about a year after the insertion of the prosthesis. Bone grafts are clearly seen in the fenestrations and there are areas of increased density about the prosthesis. (Courtesy of Dr. J. W. Fredette, Pittsburgh, Pennsylvania.)

Of the remaining ninety-six cases, fifty-five patients underwent sixty-one operations and have been followed for two to six years.

There were thirty-five females and twenty males in this group.

The ages of the patients varied from fifteen years to eighty-nine years. The majority were between sixty and seventy years old.

There were six patients between fifteen and twenty years of age. Treatment of these young patients was part of the State Crippled Children's Program. Four of the six patients were severely crippled with slipped epiphyses. The prosthesis was inserted bilaterally in one of the four. Another was a young girl severely crippled with generalized arthritis and ankylosis of both hips. Previously, bilateral cup arthroplasty had been performed. Pain was relieved by substituting prostheses for the cups. When she was seen six years after surgery, she had improved remarkably.

These operations upon young patients were done as salvage procedures. So far, the results appear to justify the surgery, and these young patients will be followed with especial interest.

FIG. 10-A FIG. 10-B FIG. 10-C FIG. 10-D

Figs. 10-A through 10-D: This spry little lady, eighty-six years old, weighing about 100 pounds, was operated upon five years ago. A prosthesis was inserted following a high subcapital fracture of the neck of the femur. She has walked without support since two days after surgery. She climbs stairs, does her housework, walks rapidly with no limp and no pain. Overexercise produces some pain. She has full normal function of the hip and she says that she "cannot tell one hip from the other".

Fig. 10-A: Full abduction.

Fig. 10-B: Patient standing on right foot; left hip is in full flexion.

Fig. 10-C: Patient standing on left foot; right hip is in full flexion.

Fig. 10-D: Patient climbs stairs easily.

FIG. 10-E

Roentgenogram made five years after surgery shows the bone reaction to the prosthesis. There is increased density under the collar, along the calcar femorale, in the fenestrations, about the lower portion of the prosthesis, and under the tip of the stem. The loop of the prosthesis was removed to prevent its impingement against the rim of the acetabulum. The loop was lowered in later models. Full abduction of the thigh is now possible.

Results

Results were classified as *excellent* (little or no pain, no limp, 100 per cent motion, 90 to 100 per cent normal hip function); *good* (mild pain, slight limp, 100 per cent motion, 75 to 90 per cent normal hip function); *fair* (moderate pain, moderate limp, 60 to 75 per cent motion, 60 to 75 per cent normal hip function); *poor* (moderate pain, severe limp, 40 to 60 per cent motion, 40 to 60 per cent normal hip function); and *failure* (Table I).

TABLE V

PROSTHESIS SIZES

2⅛ inch head size	6
2 inch head size	12
1⅞ inch head size	29
1¾ inch head size	11
1⅝ inch head size	3
Total	61

Diagnosis

There were sixteen different diagnoses. In the large majority, these were acute fractures, fractures with non-union, and osteo-arthritis with or without aseptic necrosis (Table IV).

Head Sizes of Sixty-One Prostheses Used in Fifty-Five Patients

Approximately 80 per cent of the prostheses used were large sizes — one and seven-eighths inches, two inches, and two and one-eighth inches. There were half as many prostheses sized two and one-eighth inches as two inches. Approximately 50 per cent of the fifty-five patients required the one-and-seven-eighths-inches prosthesis. This is interesting, since the prostheses which were used were considerably larger than those which are frequently recommended and are available (Table V).

Limp and Support

Patients who have been fitted with hip prostheses are advised to restrict their diets and to "take it easy" for the rest of their lives. They are advised to avoid excessive stress in the same way that one who uses a dental prosthesis avoids excessive chewing of hard or tough food which will cause soreness or pain. It has been demonstrated that excessive exercise or weight-bearing will cause soreness or pain about a hip prosthesis, which rest will relieve. All patients are advised to use a cane the balance of their lives, and frequently a Canadian crutch is recommended.

Since no important muscle attachment is divided in this operation, most patients have only a slight limp. A few patients have no limp and have practically normal function. This exceptional result should not be looked for, however, since no artificial appliance can be expected to function in the same manner as the normal hip.

SUMMARY AND CONCLUSION

Great judgment should be exercised in the selection of patients for replacement of the femoral head and a careful postoperative program should be planned. The importance of partial weight-bearing for a period of at least six months should be emphasized, with a gradual increase as roentgenograms show the reaction of bone about the prosthesis. New-bone formation takes place within the fenestrations of the prosthesis. Once this has occurred, the stem cannot be removed without chiseling away the new bone. The prosthesis becomes, literally, self-locking. It is very interesting to see, roentgenographically,

the increasing density of bone in and under the prosthesis in the stress-bearing locations. If a prosthesis is to last indefinitely, it must be constructed in such a way that stress is distributed so as to produce a dynamic reaction, in accordance with Wolff's law. In this way, there gradually occurs a thickening of bone about the prosthesis enabling it to carry the normal load of weight and stress. The prosthesis becomes a part of the living bone.

Five years ago a preliminary report was made of our experience with a self-locking Vitallium prosthesis in thirty-three patients[2]. The present report reviews the same experience in 153 patients and in 159 operations during a period of six years.

There have been no fractures of the bone in applying the prosthesis, and no dislocations of the hip have occurred during the operation.

Apparently Vitallium is inert in the tissues, and it is possible that the prosthesis may last indefinitely.

Patients are made to understand that no artificial replacement can be expected to function as well as the normal hip and are urged to be careful. They are advised to always carry a cane or to use a light support.

An attempt is being made to follow all patients. Time has already shown conclusively that transplanted cancellous bone in the medullary canal undergoes metaplastic changes and that the bone becomes progressively denser in the areas of stress. Time has also shown, as was anticipated, that there is hyperplasia of bone in, under, and about the prosthesis when weight-bearing is properly applied.

Excessive weight-bearing stress or too short a stem results in pressure necrosis with a loose, clicking prosthesis and pain. With the stimulating stress of gradual weight-bearing, areas of increased density of bone appear about the prosthesis consistent with known mechanical and engineering principles.

When patients have been properly selected and when operation has been correctly performed, and postoperative follow-up care has been conscientiously carried out, this prosthesis appears to become a part of the femur and to carry the normal stress load of weight-bearing with minimal degenerative changes and with minimal pain.

The results so far are encouraging, and the increasing number of patients bears witness to growing confidence in the procedure.

Final results can be known and a thorough evaluation of the method can be made only after many years of experience.

NOTE: For their help, I wish to express my sincere appreciation to my associate Dr. G. A. Barnaby, to Mrs. Robert C. Fennell, Jr., and J. Maxwell Chappell, our office assistants, to Dr. V. L. Krueger, Staff Physician of the Columbia State Hospital, Mr. Jack Boineau, medical student and artist, and Mr. C. L. Wise, Chief X-ray Technician and photographer.

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Surgical Repair in Recurrent Dislocation of the Ankle Joint

BY HAROLD G. LEE, M.D., BOSTON, MASSACHUSETTS

Tenodesis combined with the construction of a new ligament to replace damaged fasciculi is generally regarded as effective treatment of the severe form of lateral instability of the ankle joint. There are several such methods of repair in use, the majority of which are based upon the principle underlying the Watson-Jones operation, which utilizes the tendon of the peronaeus brevis for ligamentous reconstruction. It is because certain technical difficulties are encountered in carrying out the Watson-Jones procedure that modifications of the operation have been proposed.

The method described here is also similar in principle to the Watson-Jones operation. It is, however, simpler of execution, and it has the advantage of providing, for greater protection against inversion of the foot, a firm sheet of fascia and retinaculum, turned down as a flap and anchored over the newly constructed ligament. The author used this method for the first time in 1944, and since then seven patients with pronounced lateral instability of the ankle have been treated successfully.

ETIOLOGY

Recurrent dislocation or subluxation of the ankle originates, in the majority of cases, with a severe sprain of the lateral ligament. The initial injury occurs upon forcible inversion of the plantar-flexed foot. Various components of the ligament are completely ruptured, and the talus dislocates momentarily from the ankle-joint mortise. If the ligament should fail to heal or should become stretched in the healing process, the ankle will be weak and unstable.

Not infrequently, these serious ruptures of the ligament are mistaken for minor sprains in which fasciculi are merely stretched or a few fibers torn, and, hence, are inadequately treated. At times, the diagnosis may be accurately established, but the complete ligamentous tear is treated by strapping and massage as a simple sprain, and the patient is permitted to bear weight early. Complete ruptures can be diagnosed only by demonstrating a tilting of the talus in the ankle-joint mortise, which is shown in an anteroposterior roentgenogram made with the foot in the position of plantar flexion and maximum inversion.

The choice of treatment for a severe sprain of the ankle varies with the individual surgeon. Many suggest open repair when gross rupture of the lateral ligament has occurred. Others prefer to try rigid immobilization for a sufficient period of time to ensure healing of the ligament. Although the prognosis is good under the latter management, faulty healing and a chronically weak ankle occasionally results. Indication for primary surgical repair is not recognized by the author at the present stage of treatment of these lesions.

Complete tears of the external lateral ligaments are fairly common injuries. Leonard, in a roentgenographic study of fifty-one severe inversion sprains, observed a tilting of the talus, indicative of a complete tear of one or more components of the lateral ligament, in twenty-three instances. Hughes noted a varying degree of tilting of the talus in twenty-nine of fifty-seven consecutive ankle injuries studied by roentgenograms. In approximately 25 per cent of these cases, the tilting was of sufficient degree to cause recurrent subluxation of the ankle. Petersen observed tilting of the talus, indicative of ligamentous rupture, in 11 per cent of 109 recent injuries of the ankle.

There is still no general agreement as to which components of the ligament, or as to how many of its fasciculi, are ruptured in cases of subluxation of the talus. Some investi-

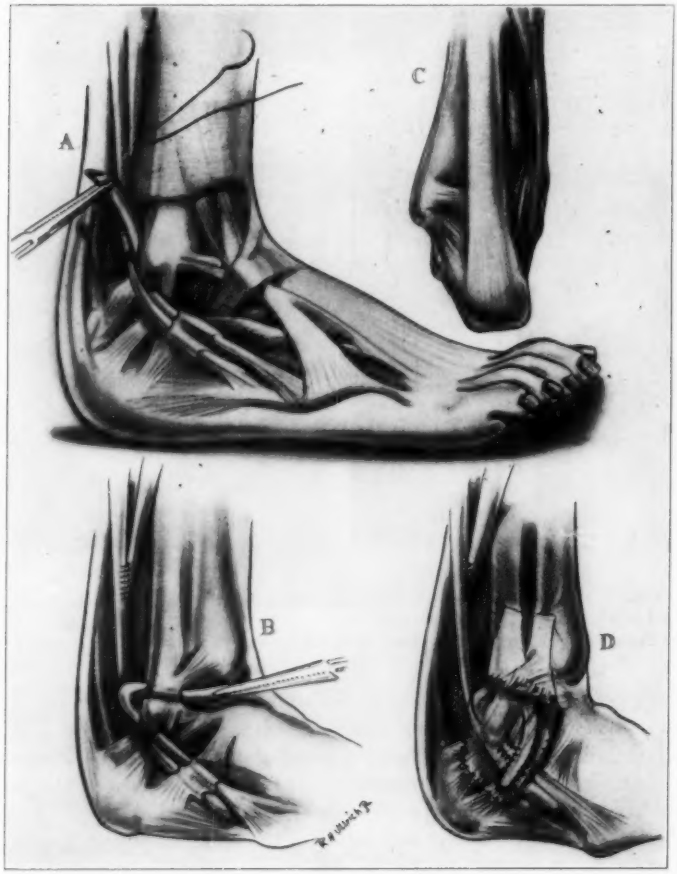

FIG. 1

Operative technique: *A*, division of peronaeus brevis tendon; *B*, lateral view, showing suture of the peronaeus brevis muscle fibers to the peronaeus longus, and the distal end of the tendon passed through a drill hole in the external malleolus; *C*, posterior view; *D*, suture of the peronaeus brevis tendon to itself and to the sheath of the peronaeus longus. The fascial flap, stripped from above, is sutured over the newly constructed ligament.

gators are of the opinion that the anterior talofibular ligament is most important to the maintenance of talotibial stability; others believe that the calcaneofibular component is the strongest ligament. Experimental studies indicate that the tilting of the talus is increased when there is associated rupture of two or three components.

A second cause of instability of the ankle is a relaxed lateral ligament which permits movement exceeding physiological and habitual limits. In some instances the weak ligament may be congenital in origin; in others, the cause is unknown.

Occasionally, laxity of the ankle may be encountered in which the instability of the joint has developed subsequent to surgical treatment of another lesion, as in two instances in the series being reported.

SYMPTOMS AND DIAGNOSIS

The chief complaint of a person suffering this lesion is weakness and instability of the ankle. The joint "gives way", often on slight provocation. Derangement occurs

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 1. Preoperative roentgenogram showing tilting of the talus in the ankle-joint mortise when the foot is inverted and plantar flexed.

Fig. 2-B: Roentgenogram made five years after the operation, showing no abnormal tilting of the talus.

usually when a person makes a misstep or is walking on rough ground, but in severe cases the foot may invert sharply even on a smooth surface. Falls are not uncommon. This lesion, which causes a person to be wary of being active, may be the source of grave disability. Participation in sports is impossible; in certain occupations the feeling of insecurity of the ankle can represent complete incapacitation.

It is not unusual for recurrent dislocation of the ankle to escape diagnosis, because a routine examination, roentgenographic as well as clinical, fails to reveal any irregularity indicative of the lesion. In the instance of one of the patients in this series, who had a severe lesion, the symptoms had been attributed to a weak ankle and treatment over a period of four years had consisted in strapping the joint.

The diagnosis in traumatic cases is suggested by the history of an acute sprain followed by recurrent sprains of varying severity. Other patients, however, present the simple history of repeated twistings of the ankle and a feeling of instability.

The manifestation that is pathognomonic of the lesion is an abnormal tilting of the talus in the joint mortise upon plantar flexion and inversion of the foot at the subtalar joint. In the average normal foot, the malleoli hug the talus upon this movement of inversion. Some ankles may normally show a slight degree of tilting on inversion of the foot because of relaxation of the talofibular syndesmosis; in such cases the instability is bilateral. A talar tilt of more than 5 degrees is indicative of disruption of the ligamentous structure and may be considered pathological.

A roentgenogram demonstrates clearly the presence of any tilting of the talus. An anteroposterior view of the entire foot, not just the fore part of the foot, in the position of maximum inversion and plantar flexion should be obtained (Fig. 2-A). As a rule, no anaesthesia is required for this examination. A roentgenogram of the opposite foot in the same inverted position should be obtained for purposes of comparison.

It is sometimes possible, when the instability of the ankle is pronounced, to demonstrate clinically an abnormal rocking of the talus by plantar flexing and inverting the foot.

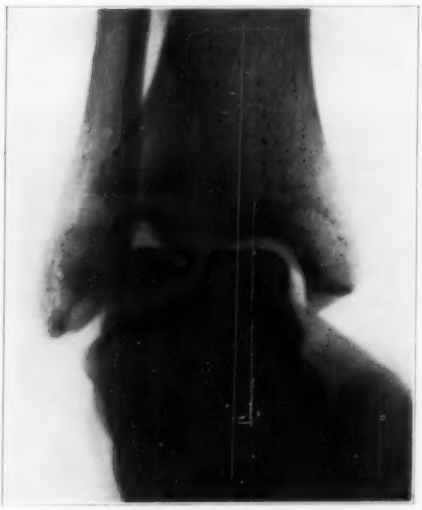

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 2. Preoperative roentgenogram showing slight tilting of the talus with the foot in the inverted and plantar-flexed position.

Fig. 3-B: Roentgenogram made approximately five years after the operation, showing no abnormal tilting of the talus.

In such instances a definite sulcus may be palpated between the talus and the external malleolus. Anaesthesia is seldom required in making this test, because the lateral structures of the ankle are not sensitive unless a sprain has been suffered recently.

TREATMENT

Ankle instability in some of the milder cases may be controlled by wearing a shoe that is built up on the outer side to evert the foot slightly and by strengthening the peroneal muscles by exercises. Such measures are not efficacious in severe cases, and the patient must choose between wearing a boot with an iron permanently and the alternative treatment of surgical repair. Operative reconstruction of the damaged ligament should always be considered when the patient is a young, active adult or when his occupation depends on a stable ankle.

Operative Technique

An incision is made on the posterior aspect of the lower portion of the leg, following the outline of the peroneal tendons and extending downward to the margin of the cuboid (Fig. 1).

The peronaeus brevis tendon is divided, after being stripped from its muscle belly in order to obtain sufficient length of tendon to construct the new ligament. The muscle fibers are sutured to the neighboring portion of the peronaeus longus. The distal portion of the peronaeus brevis tendon is freed as far down as the superior peroneal retinaculum, care being taken not to disturb these annular fibers.

A drill hole, one-quarter inch in diameter and running horizontally, is made in the lateral malleolus, just below its broadest part. No drill hole is made in the neck of the talus, as in the Watson-Jones procedure, an operative detail which is sometimes difficult to carry out because of the thin bone structure in this area.

The detached peronaeus brevis tendon is threaded through the drill hole from back to front, and its end is carried downward to below the lateral malleolus, where it is

FIG. 4-A

FIG. 4-B

Fig. 4-A: Case 3. Preoperative roentgenogram showing abnormal tilting of the talus when the foot is inverted and plantar flexed. An talonavicular arthrodesis had previously been performed for flat-foot.

Fig. 4-B: Roentgenogram made nine years after the operation, showing no abnormal tilting of the talus.

attached to itself and to the sheath of the peronaeus longus. While this attachment is being made, the foot is held in the corrected position of valgus. Thus a new ligament is constructed which, because of its pull upward and backward, guards against excessive inversion and plantar flexion of the foot.

A flap of fascia from the lower portions of the fibula and tibia is folded downward and attached at its circumference to the surrounding tissues. Any loose shred of tissue is also attached. The purpose of this flap, which lies over the newly constructed ligament, is to provide further protection against inversion of the foot by a firm sheet of fascia and retinaculum, turned down as a flap and anchored over the newly constructed ligament. In view of the fact that even living tendon may stretch under the strain of activity, such a safeguard is of advantage.

The wound is closed. The foot, in the right-angled position and in slight valgus, is immobilized by a plaster boot equipped with a weight-bearing sole.

Postoperative Treatment

Immobilization is continued for six weeks, the plaster being changed if necessary. Weight-bearing is permitted after ten days. Upon the removal of the plaster casing, a boot equipped with an upright and T strap may be worn, if indicated. A shoe which is built up on the outer side to evert the foot slightly may also be worn in convalescence.

Patients with sedentary occupations are able to return to work in from two to four weeks, and patients who perform heavier duties, in from two to three months. Normal motion of the ankle joint, except for a slight limitation of inversion, is regained.

ANALYSIS OF CASES

The reconstruction method described has been undertaken in seven patients with

chronic lateral instability of the ankle. Five of the patients were females whose ages ranged from twenty to fifty-six years. The two males were aged seventeen and thirty-three respectively.

Three patients presented a typical traumatic history of having sustained a severe sprain of the ankle some years previously, which had been followed by several recurrent "twistings". All three patients had been treated by the measures customarily used in managing a minor sprain.

The ankle instability was bilateral in two patients, and the cause was unknown. Both patients, one of whom had experienced inversion strains during a period of ten years and the other during a period of fourteen years, denied previous injury. In one of these patients there was a generalized destructive process of the joints. The other patient had sustained a fracture of the tip of the lateral malleolus four years prior to consulting the author, but during a fourteen-year period the ankle had twisted sixteen times. Upon operative exposure, in the latter case, loose pieces of bone were observed on the medial side of the joint and there was almost complete absence of the ligamentous structure around the fibula.

The sixth patient had a history of flat feet, for which a bilateral talonavicular arthrodesis had been performed by another surgeon when the patient was fourteen years of age. The feet had been positioned in excessive varus deformity. Subsequent to these operations, the patient had experienced repeated twisting of the right ankle on the slightest provocation, as well as swelling and pain after walking.

In the seventh patient an operation performed to remove a herniated intervertebral disc had been followed by weakness of the crural muscles on the left side. Subsequently, the patient had experienced constant turning of the ankle inward.

The common complaint of all seven patients was the repeated "giving way" of the ankle, particularly when walking on a slightly irregular surface. Several of the patients had experienced falls and no longer trusted their footing. All patients were concerned that the "twisting" of the ankle was becoming progressively worse and that the feeling of insecurity was beginning to interfere with ordinary activities.

Clinically, little evidence of the lesion could be elicited except for tenderness over the lateral area of the ankle. In only one case was it possible to rock the talus in the joint mortise when the foot was inverted. Roentgenographic examination with the foot in the inverted position demonstrated clearly that the talus tilted abnormally in all seven cases, the tilt varying from a minimum of a few degrees to as much as 35 degrees in one case.

Results

The seven cases were recently reviewed after a postoperative period varying from five to twelve years. It was possible to follow up, personally, three of the patients and to obtain roentgenograms of their ankles. Questionnaires were sent to the other four patients, who were living at too great a distance to report for examination.

The three patients who were examined personally were the youngest in the group; at the time of the operative repair they were aged seventeen, twenty, and thirty-three, respectively. The follow-up examinations were made after a postoperative period varying from five to nine years. All three patients were found to have stable ankles with painless, unrestricted motion. One patient was a shipper in a factory and another was a nurse. The third patient had recently been discharged from the Air Force. While on duty he had made a 15,000-foot parachute jump without ill effects to the ankle. The preoperative and postoperative roentgenograms made of these three patients are seen in Figures 2-A through 4-B.

Three of the four patients to whom questionnaires were sent reported that their ankles were stable and had a full range of motion. One of these patients had no complaint of pain. The other two patients, who are now aged fifty-three and sixty-four, respectively, and whose ankles showed arthritic changes at the time of the operation, reported that they

experienced some pain. The fourth patient followed up by means of a questionnaire complained of a feeling of insecurity and pain in the joint occasionally. This patient is obese and suffers a generalized arthritis. All four patients had returned to their regular activities; one was a stitcher in a factory and the other three were housewives.

The seven patients were greatly pleased with the result of the operation. One patient, who had a bilateral lesion, regretted that she did not have the other ankle operated upon. When there has been a complaint of pain after the operation, it has been due to traumatic arthritis. This is a factor in recurrent dislocation of the ankle, as in any joint injury, and the pathological changes are consistent with the age and weight of the patient and depend upon the length of time the lesion has continued.

SUMMARY

1. Lateral instability of the ankle may be the source of serious disability.

2. The various causes of the lesion are discussed.

3. Attention is called to the pathognomonic feature of the lesion—abnormal tilting of the talus in the joint mortise when the foot is plantar flexed and inverted at the subtalar joint. This is demonstrated in an anteroposterior roentgenogram.

4. The author describes a modification of the classic Watson-Jones operation of tenodesis combined with reconstruction of the external lateral ligament. This method, which is simpler of execution, has the added advantage of providing greater protection against inversion of the foot by a firm sheet of fascia and retinaculum turned down as a flap and anchored over the newly constructed ligament.

5. Seven patients with chronic instability of the ankle have been treated by the author's method with good results.

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Impingement Exostoses of the Talus and Tibia *

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In the course of treating a relatively large number of athletes, my attention has been drawn to a condition about the ankle which, while it seems to be relatively common, has apparently received little attention. This condition is the piling up of osteochondral ridges, or exostoses, just above the anterior lip of the lower articular surface of the tibia and on the apposing area on top of the neck of the talus. I have called this condition impingement exostoses of the talus and tibia. This same type of condition may develop in other areas about the ankle, particularly in front of the medial malleolus or in front of the lateral malleolus, and in rare instances it has also developed posteriorly. The condition discussed in this presentation, however, is confined to those exostoses which develop on top of the neck of the talus and just proximal to the distal anterior articular margin of the lower end of the tibia.

FIG. 1

Roentgenograms showing the area of apposition between the tibia and talus. Left: the foot in a neutral position. Center: the foot in dorsiflexion. Right: the foot in hyperdorsiflexion.

It will be recalled that in extreme dorsiflexion of the foot, the anterior lip of the tibia nestles into the sulcus which is located on top of the talus between its body and head. It should be noted that the leading edge of the lower end of the tibia normally inclines backward in order to prevent impingement against the talus during dorsiflexion (Fig. 1). There actually is no true ligamentous attachment at either of these locations. The anterior capsule of the joint attaches slightly higher on the tibia and runs forward to the navicular with no attachment to the superior surface of the neck of the talus. Spur formation in this region is the result of the occurrence of direct trauma during forcible dorsiflexion of the foot on the leg; it is not the late result of a ligament injury caused by extreme plantar flexion at the ankle. The injury occurs, not during ordinary running, but during the "drive" of the athlete when his cleats are fixed to the ground with the foot forcibly dorsiflexed and the neck of the talus in direct apposition to the tibia.

In many instances, much more often than is usually noted, the reaction to direct trauma during such "driving" running is the formation of bone; the reason for this reac-

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FIG. 2-A FIG. 2-B

Fig. 2-A: Roentgenogram showing talar and tibial spurs that are +++.
Fig. 2-B: Roentgenogram showing the impingement that occurs when the foot is dorsiflexed.

tion apparently is similar to the reason for the formation of calluses on the skin. This reaction has an adverse rather than a protective effect, however, for the more bone that is piled up, the more easily the impingement occurs, and so a vicious cycle is formed resulting in gradually increasing disability.

Characteristically, the player loses his "drive". As a rule, he has rather vague complaints which do not seem sufficient to account for his disability. Ordinary examination reveals little; there is no swelling, no pain on inversion or eversion, and no tenderness around the malleoli. The impression grows among teammates and coaches that the player is "dogging it". This is especially likely since he can often run, cut, and jump without pain so long as he does not go at full speed. The result may well be disappointment of the coaches, disheartenment of the player, and the ultimate blighting of an otherwise promising athletic career.

Such a patient presents himself with a history of aching pain in the ankle sharply increased by "driving", often to the point that the patient feels he cannot "go all out". He is unable to explain his failure to get that extra push that differentiates the star from the ordinary athlete. He simply realizes that his previous speed and force have been unaccountably diminished.

Examination will almost uniformly elicit one particular finding. This finding is pain on forcible dorsiflexion of the foot, an impingement type of pain located at the anterior talotibial sulcus. Roentgenographic examination will reveal that the anterior margin of the lower end of the tibia has lost its rounded character and that the edge is sharp, often with an identifiable exostosis extending forward over the articular surface of the talus (Figs. 2-A and 2-B). The condition may vary from a simple change in contour to a spur a centimeter or more long. This spur extends along the whole width of the bone and is in reality a shelf rather than a spur. In addition, an exostosis of a greater or lesser size may appear on the top of the neck of the talus. Upon dorsiflexion of the foot, the two will be seen to impinge (Fig. 2-B). Either one or both of these exostoses may be present.

These prominences are relatively small in the early stages but may be tremendous in the later stages, at which time the diagnosis becomes obvious (Case 7). The condition may extend onto the front of the medial malleolus and, rarely, to the anterior edge of the fibula; in severe cases it may also occur in other areas of the foot in which there are impinging bones, such as the posterior part of the ankle. These exostoses are similar to, but, in my opinion, not etiologically the same as, the spurring that is found on adjacent articular surfaces, such as the metatarsal-cuneiform joints. The latter type of condition is almost always accompanied by degenerative change in the articular cartilage and actual narrowing of the joint space and so frequently falls into the category of chronic arthritic changes or so-called "marginal osteophytes". This is not the condition to which we are referring when we

speak of impingement exostoses of the talus and tibia. With a single exception, our patients had no accompanying degenerative change in the articular surfaces of the talus and the lower end of the tibia. Whatever may be the cause of the marginal osteophyte found adjacent to the articular margin and of chronic joint changes, this cause is, in my opinion, wholly different from that of the impingement exostoses described here. The one patient in our series who did have degenerative changes was D. M., a basketball player (Case 7). Reference to his case report will show that he had had a long history of pain in the joints of the left foot and that he had extensive osteophytes around the margin of the talus and the malleoli. The condition in this patient may well be described as an atypical case of impingement exostoses because of the fact that there were tremendous bony exostoses in front of the tibia and on the neck of the talus which, I believe, were superimposed over the chronic condition. The typical impingement exostosis is restricted to the anterior edge of the tibia and the neck of the talus and is not accompanied by marginal osteophytes, degenerative changes, or other signs of chronic joint involvement. This is reflected in the prognosis since the result, from an athletic viewpoint, can hardly be classed as excellent if degenerative changes in the foot and ankle or, in fact, any other changes persist. The conditions may co-exist, but one is not necessarily the forerunner of the other. When severe, the impingement exostosis may be extremely disabling, precluding athletics or any other real activity (Case A). In some instances the spur is broken off and is found as a loose body lying on top of the talar neck (Cases A and 2). As such, it may cause acute disability in an ankle already chronically impaired.

It is obvious that this condition is not confined to athletes. Any one who has to dorsiflex the ankle repeatedly—during such movements as squatting and climbing ladders—may well have this same condition. It seems doubtful that the condition is initiated by repeated mild sprain of the very weak anterior capsule. Rather, it would appear that the reaction is initiated by repeated mild traumata caused by direct impingement and is often made severe by acute injury. There seems no question that repeated insult is the definitive factor in this progressive syndrome. The average workingman with this condition may be able to carry out relatively normal activity with minimal complaint and so be able to live with his disability. This is made more possible by the fact that restriction of activity is usually enough to relieve the symptoms. Unfortunately, most men object to permanent restriction of their activity; and, therefore, if function is impaired to the point that it interferes with normal life, surgical correction should by all means be considered. The athlete is, of course, the one to whom surgical correction has the most appeal since if he has to restrict his activity, he is no longer an athlete. On the other hand, the casual player may well prefer to give up his athletic activities rather than to submit to surgical correction. When impingement exostoses occur in young, healthy adult males, remedial surgery is often justified since it offers a good chance for complete cure.

When is surgery proper in these cases? We have operated upon eight ankles in seven athletes in a period of five years. During this period we have also seen many athletes with this condition who have not been treated by surgery. We think surgery is indicated if there is a definite impairment of ability, including: (1) pain on forcible running or driving; (2) localized pain in front of the ankle on forcible dorsiflexion of the foot; (3) pain on forced plantar flexion of the foot, again referred to the anterior talotibial sulcus; or (4) tenderness in the talotibial sulcus, with real impairment of function of the extremity. It will be noted that these symptoms are quite distinct from those of so-called chronic ankle sprain, traumatic arthritis of the tarsus, or arthritic changes in the ankle joint. In the latter cases the so-called "house-cleaning" operation for marginal osteophytes will probably prove disappointing.

In our experience, the spurs have not recurred postoperatively and relief has usually been complete after surgical removal. The earlier the treatment, the more complete the cure (Case 7). It is interesting to note that a high percentage of patients treated by surgery

gave a history of a relatively mild injury some time in the past. Actually six of the seven patients in our series gave a specific history of minor injury. This injury apparently consisted in contusion of the tibia or talus as a result of forcible dorsiflexion and caused only minor complaint at first. Since these patients were in a very active stage in life and since many of them were athletes, the presence of this injury may have been wholly coincidental. I am inclined to believe, however, that its presence was too frequent for there not to be some causative relationship. While it may be that the development of the spur precedes the occurrence of the final injury, the injury is probably the factor which makes the condition symptomatic. It is, of course, possible that a prior injury may be the initiating factor in exostosis formation.

THE OPERATION

In the ordinary case, an anterolateral approach will suffice to remove both talar and

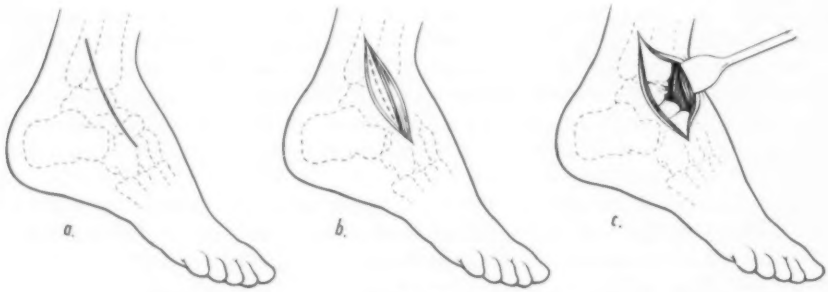

FIG. 3

Anterolateral approach: (*a*) the skin incision; (*b*) the skin has been separated, exposing the lateral edge of the extensor tendons; (*c*) the tendons and muscles have been retracted and the capsule has been opened, exposing the spurs.

tibial exostoses. However, in many cases it will be necessary to make both medial and lateral incisions, and in the occasional case (Case 2) a posterior exposure will be necessary.

Anterolateral Approach

After the usual preparation and the application of a tourniquet, a skin incision is made just lateral and parallel to the peronaeus tertius tendon, beginning about one and one-half inches proximal to the lower articular surface of the tibia and extending distally for approximately three inches (Fig. 3, *a*). The extensor tendons are retracted medially (Fig. 3, *b*), and the incision is carried through the very weak anterior capsule of the ankle joint, including the anterior fasciculus of the talofibular ligament. It is not ordinarily necessary to disturb the short extensor muscles, nor is it necessary to clean out the sinus tarsi. After the capsule has been opened, the anterior articular lip of the tibia is readily apparent, and by firm retraction the neck of the talus may be exposed (Fig. 3, *c*). By means of a sharp osteotome, the exostosis along the lower portion of the tibia is carefully removed. The front edge of the lateral malleolus is visualized, and any spurring found is also removed. The exostosis on the neck of the talus is best removed by means of a gouge which is shaped to conform to the concavity of the neck; a small osteotome is also useful. The roughened bone is very carefully smoothed out and all fragments removed. The area is then thoroughly lavaged and the raw bone surfaces are sealed with bone wax. Following this, the wound, including the divided ligament, is closed in layers.

Medial Approach

The incision on the medial side begins one inch above the lower end of the tibia, just

TABLE I

OUTLINE OF RESULTS OF SURGERY FOR TALOTIBIAL EXOSTOSES

Case	Age	Sport	Symptoms		Disability	X-ray Findings		Date of Operation	Length of Follow-up	Result
			Severity	Duration		Talar	Tibial			
1. L.H.	21	Football	+++	12 mos.	+++	+	+++	5-6-50	6 yrs.	Excellent
2. E.R.	20	Football	++	5 mos.	++	+++	+	4-26-51	4 yrs.	Excellent
3. M.G.	20	Football	+++	2 mos.	+++	++	+	4-26-51	5 yrs.	Excellent
4. J.M.	18	Football and track	++	12 mos.	++		++	9-14-51	5 yrs.	Excellent
5. R.N.	19	Football	+++	3 mos.	+++	+	++	1-25-52 12-17-52	4 yrs.	Good
6. S.W.	25	Football	+++	7 mos.	++	++	+++	5-8-52	4.5 yrs.	Excellent
7. D.M. (left)	19	Basketball	++++	48 mos.	+++	++++	++++	3-5-54	2.5 yrs.	Good
D.M. (right)			++	48 mos.	++	++	++	5-27-54	2.5 yrs.	Excellent

TABLE II

OUTLINE OF RESULTS OF NON-SURGICAL TREATMENT FOR TALOTIBIAL EXOSTOSES

Case	Age	Sport	Symptoms		Disability	X-ray Findings		Length of Follow-up	Result
			Severity	Duration		Talar	Tibial		
A. J.F.	28	Basketball	++	10 yrs.	++	+++	++++	5 yrs.	Poor
B. B.S.	17		++	36 mos.	+	+	+++	1.5 yrs.	Good
C. F.M.	19		+++	12 mos.	++	++	++	2 yrs.	Fair
D. B.C.	20	Basketball	++	1 mo.	+	++	+	None	Poor

medial and parallel to the anterior tibial tendon. The incision extends distally to the posterior edge of the navicular. The saphenous vein may be retracted by cutting either its anterior or posterior branch, and ready access may be had to the front of the ankle by opening the capsule. The procedures described in the previous section for the removal of the exostoses are then carried out.

The medial malleolus and the medial border of the talus are examined by digital palpation. If spurring is found, a portion of the deltoid ligament may be divided in order to obtain better access to the area involved. The same method of closure is used as is used on the opposite side.

Following these procedures, posterior and lateral stirrup splints are applied from below the knee to the toes with the foot in neutral lateral position and in 90 degrees of dorsiflexion. After ten days the stitches are removed and a walking cast is applied, to be worn for another ten days. Following removal of this cast three weeks after the operation, further support is used only as indicated.

An elastic bandage may be useful if swelling persists, but it is urged that active use, in fact unlimited activity, be begun as rapidly as possible.

CASE REPORTS

The cases reported here have been confined entirely to those seen in athletes. We have seen this condition in many persons who previously had been athletes but were in some other occupation when the condition was first diagnosed. We have also seen it in many persons who were never athletes. Some of these patients were treated by operation and some were not, but exact analysis of their cases must remain for a later report since in these cases there are many factors which confuse the findings. The seven surgical patients whose cases are reported here comprise all of the athletes operated upon during the period May 1950 through May 1954 (Table I). I am also reporting four rather typical cases of athletes not treated by surgery (Table II). Each illustrates a slightly different aspect of this problem and its solution. Basically, the patients not treated by operation were able to live with their disability, either with or without discontinuing their athletic activity.

CASE 1. L. H. was first seen in April 1950, following a football game. He had been having trouble with his right ankle for about a year. Every time he ran hard in a game, the ankle became stiff and sore. The discomfort would ease up during the week but would return upon active exertion. The pain was located in the anterolateral portion of the joint, and there was a region that was tender to pressure just in front of the ankle. Roentgenograms made several months previously showed some exostosis formation on the tibia and talus. On examination, it was found that the tender spot was right in front of the ankle on the lateral aspect, near the tibiofibular junction. There was no tenderness, swelling, or discoloration around the medial malleolus. There was pain on dorsiflexion of the foot and on forced plantar flexion. During spring practice, the patient had noted that if he ran "all out", he would be lame that evening and he felt that this actually slowed him down. He said he had become very lame in the game which he had played just a few days previously and had had to be taken out. Since then he had had markedly increased trouble in his foot, with pain whenever he attempted to squat or dorsiflex the foot. Roentgenographic examination revealed exostoses on the neck of the talus and along the lower end of the tibia with a fragment lying loose in the anterior compartment of the joint (Fig. 4-A). At operation (through an anterolateral incision) in May 1950, a fragment the size of a lima bean was found to have broken off from a spur on the front of the tibia and to be lying loose in the anterior compartment. This was removed and the exostoses across the front of the tibia and the top of the talus were smoothed off. The patient had a prompt and uneventful recovery (Fig. 4-B); he played several years of varsity football and is now playing professional football. In April 1956, six years after the operation, he had no restriction of motion, pain, or tenderness. He is currently playing with the Washington Redskins.

CASE 2. E. R., a twenty-year-old football player, was injured on November 18, 1950, when another player fell on his left ankle, forcibly dorsiflexing it. There was pain all through the ankle. The ankle was strapped up for a few days, and he was given whirlpool treatment. The ankle bothered him some, but he continued to play. One month later he hurt it again during scrimmage. At that time it hurt him to walk or run, particularly to run hard. The ankle appeared normal upon superficial examination. The pain was along the inner side of the lower end of the tibia and in the anterior talotibial sulcus. Subsequently it did not bother him particularly to run in an ordinary way, but he was not able to run "all out" and became lame when

FIG. 4-A

FIG. 4-B

Fig. 4-A: Case 1, L. H. The talar spur is + and the tibial spur is +++.
Fig. 4-B: Postoperative roentgenogram made June 15, 1950.

FIG. 5-A

FIG. 5-B

Figs. 5-A and 5-B: Case 2, E. R. The talar spur is +++ and the tibial spur is +. Note the lesion on the posterior aspect of the tibia, which resembles the condition seen in Pellegrini-Stieda disease.

he tried. He was preparing for a Bowl game, and there was some feeling that he was loafing, particularly since the results of an examination made at that time were relatively negative. He was able to play in the Bowl game but not at full strength, and he had increasing disability. He was seen six weeks later, at which time he had definite pain in front of the tibia and in the neck of the talus, especially upon dorsiflexing the foot. He also had pain on the back of the tibia, and roentgenographic examination showed moderate exostosis formation along the neck of the talus and on the front of the tibia, particularly toward the medial malleolus. There

was a deposition of calcium along the posterior inferior portion of the shaft of the tibia similar to that found in Pellegrini-Stieda disease (Figs. 5-A and 5-B). The disabling pain was in the anterior portion of the ankle. He was operated upon about six months after the onset of symptoms, a collar of exostosis being removed from the top of the talus and from along the anterior margin of the tibia. Through a posterior approach the calcification on the back of the tibia was also removed. I question whether this calcification was actually symptomatic, but at the time I did not feel justified in not removing it since its continued presence might have made a second operation necessary. The patient had excellent return of function following the operation, and when seen in April 1955, he had no complaints in spite of the extensive preoperative calcification. He continued to play varsity football, and following this he played professional football in the Canadian League until he was called into the Armed Forces, where he played football for two more years. He has not

FIG. 6-A FIG. 6-B

Figs. 6-A and 6-B: Case 3, M. G. The talar spur is ++ and the tibial spur is +. Note the abnormality of the os trigonum.

returned to football since he was discharged from the service, but not because of any trouble with the ankle. He is now actively coaching. In September 1956, six years after the operation, he had no complaints and the results of a physical examination were negative.

CASE 3. M. G. injured his right ankle in a college football game on December 2, 1950. There was pain on the outer side of the ankle with very little swelling. The ankle was not immobilized following the injury. The patient was given whirlpool and heat treatment, and there was some improvement at first but not much change after that. The ankle hurt when he ran hard or tried to cut. Since he was a halfback, this seriously impaired his playing ability. He was seen three months after the injury. It was difficult for him to state the exact location of the pain, but it seemed to be in front of the ankle. There was no swelling and no tenderness. Roentgenograms showed an exostosis on the talus, and there was also a less severe exostosis on the tibia (Figs. 6-A and 6-B). There was apparently some fragmentation and irritation around the os trigonum posteriorly which was asymptomatic. He was told that he should try to play but that if he could not, surgery would be recommended. He tried to play during spring practice, but his efficiency was materially reduced. He was examined again in April 1951, at which time he had mild pain on the back of the talus and more severe pain about the anterior talotibial sulcus, particularly on the lateral side toward the fibula. Roentgenograms showed some increase in the size of the spurring in front of the ankle and some degree of irritation posteriorly. An anterolateral incision was made and the collar of spurring removed from the front of the tibia and from the neck of the talus. In order to eliminate possible posterior pain, a posterior incision was also made and two fragments found back of the talus were removed. There was found to be some synovial irritation around these two pieces, which were lying loose in the posterior compartment. The patient made an uneventful recovery and had no serious trouble with his ankle that summer. He played football the next fall but hurt his knee, which kept him out of competition for the season. He was fully recovered for the next spring practice and became an outstanding star the following fall. He was last examined in September 1956, at which time he had no complaints concerning the ankle and was carrying out normal activity. He had had no recurrence of the exostoses and no restriction of motion or pain on forced dorsiflexion.

Case 4. J. W. M., aged seventeen, hurt his right ankle on December 8, 1950, while playing high-school football. He did not know just which way the ankle had turned. Examination revealed that he had a very tender and swollen ankle which was painful, particularly on dorsiflexion of the foot. He was given the usual treatment for a sprained ankle. Three weeks later he still had marked tenderness in the front of the ankle on the fibular side, just at the tibiofibular junction with the talus. The ankle was kept strapped. One month following the injury he was able to play basketball while wearing an ace bandage. When he was next seen, eight months after the injury, he stated that he had continued to have trouble with the ankle, that the condition was not severe in the sense that the ankle was swollen or that he could not walk, but that whenever he tried to exert himself strenuously, as in playing basketball or running, soreness developed in the front of the ankle. He was a track man, and the injury had interfered some with his take off from the starting blocks and also in his sprinting, which bothered him greatly since he was primarily a sprinter. Examination at that time revealed tenderness just in front of the ankle at the sulcus between the tibia and talus on the lateral side; also

Fig. 7

Fig. 8

Fig. 7: Case 4, J. M. This roentgenogram shows the outline of the exostosis along the anterior margin of the tibia.

Fig. 8: Case 5, R. N. The talar spur is + and the tibial spur is ++.

in this area, there was crepitation on motion and pain on forced dorsiflexion or eversion. Roentgenographic examination showed no pathological condition around the neck of the talus but revealed a definite exostosis along the tibia on the anterior margin toward the lateral side (Fig. 7). The patient was given the usual treatment, including strapping of the ankle, and advised to continue playing. He returned six weeks later complaining of pain in front of the ankle and on the lateral side, particularly when he tried to cut and run fast. He had not been able to play football and had been impaired in track. Since he was a candidate for the Olympic team, he was naturally eager to have the condition relieved. He was operated upon September 14, 1951. At operation, a bone formation was found along the anterior edge of the tibia, the most extensive portion being located laterally, just adjacent to the tibiofibular joint; this formation was removed. The moderate exostosis found on the medial aspect of the talus was also removed. The postoperative course of the patient was uneventful. Six weeks later the ankle looked fine, the patient had no complaints, and there was no evidence of recurrence in the roentgenograms. When examined for another condition on December 5, 1952, fifteen months after the operation, he still had no complaints concerning the ankle. Since then he has continued to have no difficulty and is a champion runner. He was a member of the 1952 American Olympic track team (400 meters), also of the 1956 team (Gold Medal, 400-meter relay). The results of the most recent examination were entirely negative.

Case 5. R. N. was first seen in December 1951. At that time he stated that two months previously he had begun to notice pain in the left ankle, particularly on the lateral and anterior aspects. It hurt all the time he was playing football, especially when he ran hard or tried to stop quickly. Since the football season had been over, the pain had eased and had not bothered him so much. Examination revealed tenderness in front of the lateral malleolus extending across the front of the tibia, and pain on dorsiflexion and eversion of the foot. He had only a minimal amount of tenderness along the tibia and fibula at the ankle joint. Roentgenographic examination showed a little spurring along the front of the tibia (Fig. 8). He was treated by conservative means. He was next seen a month later, at which time the pain was more marked along the front of the ankle and also around the medial malleolus. Since he was having continuous trouble and since he was anxious to continue playing football, surgery was recommended. This surgery was carried out January 25, 1952, at

which time the exostoses along the front of the tibia and along the neck of the talus were removed. He had an uneventful recovery. He was seen four months later; at this time he was still having some trouble in his ankle and there was some swelling. The findings of the roentgenograms were negative, however, and there was no evidence of recurrence of the exostosis. He was able to play football the following fall with only a minimal amount of trouble in the ankle, but by the end of the season he had constant pain around the outer part of the ankle. A diagnosis was made of tenosynovitis of the peroneal tendon. Since the condition did not respond well to non-surgical treatment, surgical exploration was carried out. No tenosynovitis of the tendon was found; instead there was found extensive bone formation on the adjacent edges of the calcaneus and cuboid, particularly along the talocalcaneal area on the lateral side; this formation was so extensive that it was actually impinging against the tip of the fibula. It was entirely removed, the impingement of the adjacent bones being thus completely eliminated. I did not actually explore this area at the time of the first operation and have no way of knowing whether the bone formation was present at that time. It may be said that this condition was part of a traumatic arthritic condition. However, there was no arthritis of the tibiotalar joint or of any joint around the talus. Actually, at the time of the first operation, the pain had all been in front of the joint and this had been completely relieved. Following the second operation in December 1952, the patient's progress was good. He was able to play spring football although he continued to have some complaints. The following fall, less than a year after the operation, he was a regular player on the varsity squad but had considerable complaint around the ankle. Eighteen months after the operation, he still had moderate complaint, particularly on forced dorsiflexion, with some restriction of this motion. He was able to go on playing football, however, and has continued to play, being currently with the Edmonton Eskimos. In September 1956, four years after his second operation, he said that he had occasional swelling and soreness in the ankle with occasional sharp pain in the back of the calf. In spite of the fact that he has continued to play ball, he has had a less good result than most of the athletes treated by operation. In this case there possibly was some complication in the sense that there was some traumatic arthritis around the foot in addition to the exostosis between the talus and tibia. I have classified his result as *good* since he had a slower recovery and some persistant complaint.

Case 6. S. W., twenty-five years old, injured his ankle in October 1951, while playing professional football. There was marked swelling as a result of the injury. The ankle had already been taped, but the tape was torn off at the time of the injury. He had it taped again, was given local heat treatment, and kept on playing but with a good deal of difficulty. He injured the ankle again one month later. Thereafter, it hurt him to get up on his toes and to go up and, particularly, to go down stairs. He had aching in the ankle and soreness, but examination revealed only minimal swelling. There was pain on inversion of the ankle and on dorsiflexion, the tenderness being just along the anterior border of the lateral malleolus, extending up onto the anterior lip of the lower end of the tibia. Roentgenograms showed exostosis formation along the front of the tibia and in the area of the lateral malleolus (Fig. 9-A). There was also an exostosis along the top of the talus. At operation on May 8, 1952, a pea-sized osteocartilaginous body lying free in front of the fibulotalar joint was found. This was a fragment from the tibial spur. The exostoses on the lower end of the tibia and along the anterior lip of the lateral malleolus were large. There was a fibrocartilaginous band interposed between the lateral malleolus and the talus; this had developed in response to the trauma as a mechanism to separate the opposing surfaces, functioning in much the same manner as a meniscus. I have seen this in several ankles. It is not directly related to spur formation. The exostoses were completely removed, also the fibrous band. A second incision was made and the exostoses from the anteromedial portion of the tibia were removed. The usual closure was done and a splint was applied. The splint was maintained for three weeks, and the patient was then advised to start walking. By four weeks after the operation, he had pain-free motion (Fig. 9-B), and he has had no trouble with this ankle since. He has continued to play professional football, being one of the outstanding linemen in the past several years. He was last examined in September 1956, four and one-half years after the operation, at which time the findings were entirely negative, there being no pain even on forced motion. He is currently playing on the Chicago Cardinal professional football team.

Case 7. D. M., nineteen years old, was a basketball player. In 1950, he had jumped off the top of a car onto some hard cinders, landing on his feet. He was not actually disabled after this, but his feet were rather sore for some weeks and continued to bother him thereafter. He wore arch supports, but these gave only slight relief. Examination at this time revealed that there was pain through the dorsum of the foot and that he had mild flat-foot. He was seen again three years later, at which time he complained of increasing trouble, particularly with the left foot, with pain on attempting to run hard or jump. He had been playing on the varsity basketball team but with a good deal of difficulty. Examination at this time revealed pain on dorsiflexion or plantar flexion with restricted motion in the left ankle. There was also some pain in the right foot and ankle, but it was not nearly as severe. Roentgenograms made at this time showed extensive exostoses, both tibial and talar; these exostoses were much more marked in the left foot (Fig. 10-A). He was advised he should have surgery but wanted to go ahead and try to play. He continued playing until March 1, 1954, when he was forced to stop and returned for surgery. At the time of examination preliminary to surgery, he had very restricted plantar flexion and dorsiflexion of the left foot and had severe pain on attempting to

FIG. 9-A

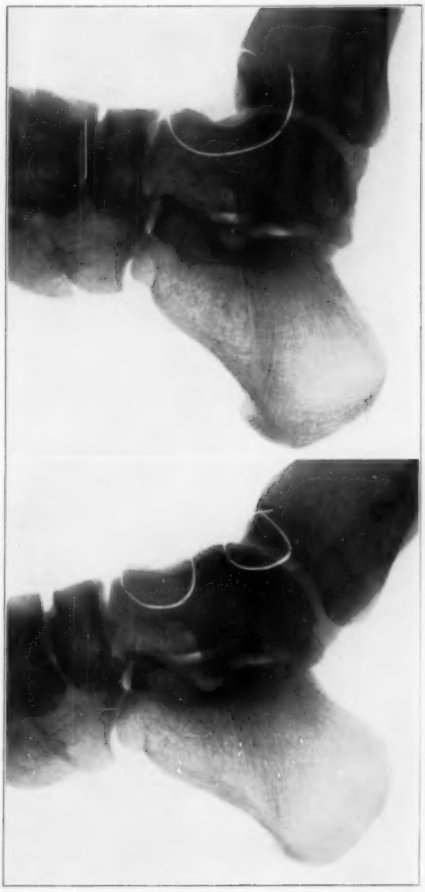

FIG. 9-B

Fig. 9-A: Case 6, S. W. The talar spur is ++ and the tibial spur is +++. Note the loss of posterior inclination at the front of the tibia.

Fig. 9-B: Postoperative roentgenograms made June 2, 1952, showing the excellent result.

"drive" or jump so that he had been having to play "flat footed". He could not run or drive. The disability in the right foot was not nearly so severe but there were the same general symptoms. The left ankle was operated upon March 5, 1954. A very extensive collar of bone was found extending all around the talar neck and in front of the tibia and amounting really to a shelf (Figs. 10-C and 10-D). This bone formation appeared to consist of bone exostoses. One piece the size of a large pea was found broken off and lying in the anterior compartment of the ankle. The spurring extended down along the front of the fibula and also around onto the medial malleolus. The whole area was smoothed off with a chisel and gouge, care being taken to leave the area as clean as possible. The denuded area of bone was covered carefully with bone wax, the wound was closed, and a plaster cast was applied. The patient wore this cast about three weeks; it was then removed and active motion started. Very marked improvement in the condition of the ankle was obtained even in this short length of time.

Because of the marked improvement in the left foot (Fig. 10-B), he returned three months later for operative treatment of the right foot. At operation on May 27, 1954, it was found that the symptoms in this foot were essentially the same as those in the left foot but were less severe; exostoses were found along the neck of the talus and along the corresponding part of the tibia (Fig. 11). The surgery performed in this foot was similar to that done on the left foot. Following surgery, the ankle was kept in a cast for three weeks; the patient was then allowed to walk. On July 8, 1954, four months after the operation on the left ankle and six weeks after the operation on the right, he had excellent motion in both feet with some aching but with no pain on forced dorsiflexion or on attempting to "drive". In September 1956, two and one-half years after the operation, he still had considerable difficulty, particularly in the left, more severely affected ankle. It should be noted that this case is not a typical one, although it illustrates excellently the nature of exostoses. The exostoses in this patient were very much more severe than those seen in the average patient. This case constitutes good evidence for early surgery, for the result would probably have been substantially better, particularly in the left foot, had the patient been operated upon sooner. The patient is now out of school; he is no longer playing basketball but is coaching. The left foot gives him considerable difficulty in that it feels weaker and there is some numbness of the skin on the top of the foot. On examination of the left foot, it was found that he had normal flexion and extension with no pain in the ankle joint, but that he still had considerable pain through the arch of the foot and is wearing arch supports. It will be recalled that he has flat-foot in addition to the other trouble. The result in the right foot is excellent, there being a full range of motion with

FIG. 10-A

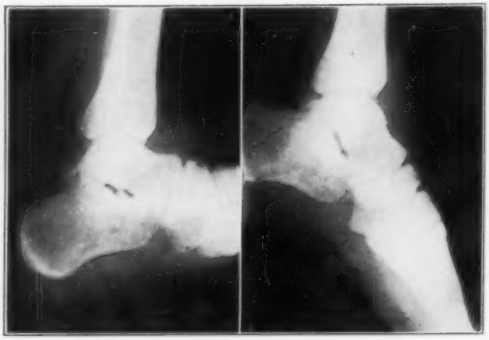

FIG. 10-B

Fig. 10-A: Case 7, D. M., left foot. The talar spur is ++++; the tibial spur is also ++++.
Fig. 10-B: Postoperative roentgenograms showing the range of flexion and extension.

FIG. 10-C

FIG. 10-D

Fig. 10-C: Photograph showing the total amount of material removed. The spurs in this case were much more extensive than those in the average case.
Fig. 10-D: The excised tibial and fibular spurs superimposed on tracings made from a roentgenogram of the ankle of the patient.

no pain. We classified the result in the left foot as *good* rather than *excellent* because he still does have considerable difficulty with this foot, although actually this difficulty does not appear to be so much the result of the exostoses as of the static flat-foot.

The following cases have been selected from the large series of patients seen between 1950 and 1955 who were not treated by surgery.

CASE A. J. F. was twenty-eight years old when first seen in September 1951. Eight years before, while playing basketball, he had twisted the right ankle. Following the injury he had worn a cast for from four to six weeks but had received no other treatment. The ankle had not bothered him too much except that he was unable to fully dorsiflex his foot. He had the feeling that his heel cord was tight. At examination in September 1951, his only complaint was that the right ankle had become more painful during the previous several days. Examination showed some apparent enlargement of the lateral malleolus, extending to the front of the tibia. The foot would dorsiflex to almost 90 degrees. There was local elevation in temperature in the ankle, tender-

ness in the talotibial sulcus, and pain on forced dorsiflexion of the foot. Roentgenographic examination revealed extensive bone formation along the front of the tibia and neck of the talus and along the front of the lateral malleolus (Fig. 12-A). The patient was treated by such means as an elastic bandage, local heat, and local injection and obtained some relief. He was examined thirty months later, at which time he was having increased trouble with the foot. He noticed this particularly when it was cold. The complaint consisted of soreness in front of the ankle and stiffness and tightness in the heel cord. He was advised at this time that the most appropriate treatment would be surgical excision of the calcified mass and that he could probably expect increasing trouble until this was done. Since he no longer participated in active sports, however, he decided to try to see if he could get along without surgery. On examination in 1954, three years later, he stated that he had been having increasing trouble with the right foot and had had to give up any physical activity such as golf. He was given the usual treatment, was again advised that he should have surgery, and again refused. He was examined in September 1956, five years after my first examination, at which time he was having increasing trouble with the right foot and there was marked restriction of motion and impingement of the exostoses between the tibia and talus. He had been able to get along by cutting down his physical activity. At times even prolonged walking would bother him. A comparison of roentgenograms made in 1956 (Figs. 12-A and 12-B) with those made in 1951 revealed that the extensive spurring which had been present on the anterior portion of the tibia in 1951 had fragmented, one large piece being broken off. There was also an increase in the spurring on the talar neck. The range of motion in this ankle was markedly limited. I think this patient should have had surgery. The exostoses are so extensive that traumatic arthritis will inevitably develop, although until now there has been no actual narrowing of the talotibial joint. In this case relief was not obtained by discontinuing athletic activity.

FIG. 11

Fig. 11: Case 7, D. M., right foot. The talar and tibial spurs are both ++.

CASE B. S., a seventeen-year-old football player, was seen in December 1954, having had frequent episodes of lameness in the right ankle. For reasons he did not understand, he could not run hard or really drive. His playing was not otherwise materially affected, however, for he was able to punt and place kick. He had found that complete relief was obtained by strapping his ankle tightly enough so that dorsiflexion was somewhat restricted. After he recovered from a relatively acute episode, he removed the tape and would get along very well until hyperdorsiflexion of the foot again caused irritation. A lateral roentgenogram revealed exostoses on top of the neck of the talus extending to the head of the talus and definitely impinging against the lower end of the tibia on dorsiflexion (Fig. 13). He continued to play high-school football and did an excellent job. Several times in each season he had episodes of lameness, and he felt that the ankle impaired his efficiency somewhat. He had been able to continue playing without surgery by careful strapping of the ankle in order to restrict dorsiflexion, thus keeping his symptoms to a minimum. He probably would have obtained more complete relief if surgery had been done. In September 1956, he reported that he had stopped trying to play college football for reasons not directly attributable to the ankle.

CASE C. F. M., a nineteen-year-old athlete, presented himself on November 11, 1954, with a complaint of pain in the left ankle. For a year the ankle condition had been diagnosed as a sprain. He played basketball and track. While playing basketball he had noticed that it hurt him to jump or drive. Taping the ankle had helped, although it had restricted dorsiflexion. An arch support fitted into his shoe had given him no relief. On examination, it was found that dorsiflexion was limited to 90 degrees and that there was pain in the talotibial sulcus. He was primarily a track man and said that the ankle did not bother him when he ran but did hurt him as he came out of the blocks. Roentgenographic examination showed rather typical talar and tibial spurs, with no evidence of fragmentation or of any real joint irritation (Fig. 14). He was advised that he could have the spurs removed or that he could try taping his ankle so that he could run. He decided to try taping and went through the 1955 track season with no difficulty except for a moderate degree of limping. On examination in October 1956, he reported that he had discontinued college sports and had had no further trouble with his ankle. He had done some running that summer at camp and the ankle had bothered him very little. It was found that he had tenderness over the neck of the talus anteromedially and that there was moderate tenderness along the front of the tibia when deep pressure was applied; ordinarily he was not conscious of any pain in that area. He had no restriction of dorsiflexion or plantar flexion, and there was no pain when

FIG. 12-A

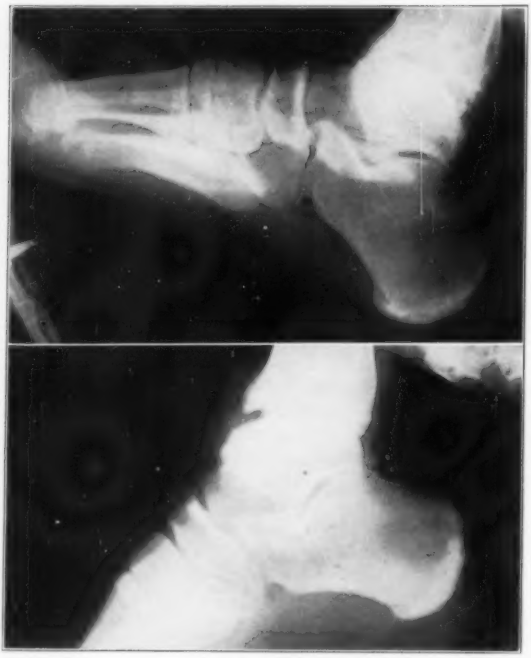

FIG. 12-B

Fig. 12-A: Case A, J. F. Roentgenogram made in 1951, showing the severe untreated spurs.

Fig. 12-B: Roentgenograms made in 1956. The spurring has increased, and there is fragmentation of the tibial spur, a finding which was noted at operation in Cases 1 and 6.

he stood on his toes or squatted down. When last seen, he was twenty-one years old and had definitely given up track. I think he will probably continue to have no disability in this ankle, for roentgenograms made two years after the first examination showed no change in the spurs.

CASE D. B. C., a basketball player, was first seen November 16, 1950, a few weeks after he had begun to have pain in his left ankle. His ankle hurt most when he jumped up and down. He said that his ankles had always been weak and that he taped them when he worked out. He had no swelling. The complaint in the ankle was in front of the talus just between the talus and tibia and also behind the medial malleolus. There was pain on plantar flexion of the foot and ankle and on forced dorsiflexion of the foot. Roentgenograms showed some spur formation along the top of the talus, at the point where the tibia and talus impinge (Fig. 15). There was also minimal involvement of the tibia. The conclusion was that he had talotibial exostoses. He was advised that if local therapy and strapping did not provide relief, the spurs should be surgically removed. He never returned for further examination. On checking up on him later, it was found that he had not finished out the basketball season and that he had dropped out of school. This boy controlled his ankle symptoms by eliminating their cause, namely forced activity. Although I have been unable to reach him recently, I have been informed that he has discontinued athletics and is getting along quite well.

DISCUSSION

Dr. T. P. McMurray, in one of his last publications, reported three cases of this condition. He claimed that the condition was caused by injury to the foot during kicking, his patients all being soccer players. He also referred to an unpublished discussion by Mr. L. H. Morris, given before The British Orthopaedic Association in 1943. In this discussion Morris reported the occurrence in five athletes of a condition he called "athlete's ankle", which he thought was due to traction trauma resulting in calcification of the dorsal ligament. None of Morris' patients were treated by surgery. McMurray's three patients were treated by operation and the condition found was described as calcification within the capsule. This description is contrary to my findings which reveal a definite osteochondral mass piled up along the joint margin; in many cases, particularly when the condition occurs on the tibia, it is similar to the marginal osteophytes commonly found at the knee. (McMurray's one roentgenogram definitely seems to indicate that the condition was an

exostosis rather than calcification of the ligament.) I have seen one or two cases in which there was definite calcification within the anterior capsule of the joint. In one of these cases this was accompanied by spurring along the front edge of the tibia and neck of the talus; in my opinion, the calcification was a separate condition and not an impinging exostosis. We have seen a few cases in which there were calcium deposits within the capsule of the joint; these deposits were of a creamy consistency and appeared to be degenerative changes rather than spurs. I do not believe these deposits occur in most cases, however, and so have not included them in my description of the characteristic symptoms.

I doubt very much that extreme plantar flexion of the foot is actually the etiological factor since this would imply the occurrence of traction or repeated sprains of the anterior ligament or capsule. Since the spurs do not arise at the ligamentous attachment and do not appear within the ligament, it also seems unlikely that repeated strain is the etiological factor. This may be a somewhat academic discussion since the treatment (surgical excision) is the same regardless of the etiology.

In order to determine the validity of the above assumption, it was decided that a relatively long series of ankles should be studied in order to determine whether such exostoses are more frequent (even though non-symptomatic) in those who are most subject to dorsiflexion trauma, namely, athletes. We accordingly made lateral roentgenograms of 120 ankles of student athletes and 120 ankles of student non-athletes. The division between athletes and non-athletes may be fairly artificial since in some sports, for example wrestling, the ankle may not be subjected to much trauma, while in some non-athletic activities, the ankle is as subject to trauma as it is in football. However, in a large group the discrepancies should be averaged out sufficiently to indicate whether or not excessive activity is a contributing factor to the formation of exostoses.

FIG. 13

Fig. 13: Case B, B. S. This roentgenogram shows typical impinging talotibial spurs which were mildly symptomatic. The talar spur is +++ and the tibial spur is +.

Fig. 14: Case C, F. M. The talar and tibial spurs are both ++.

Fig. 15: Case D, B. C. The talar spur is ++ and the tibial spur is +.

FIG. 14

FIG. 15

The over-all percentages show that only 55 per cent of the athletes' ankles had no exostoses while 84 per cent of the non-athletes' ankles had no exostoses (Table III). Even more significant is the finding that while 27.5 per cent of the athletes' ankles had both tibial and talar involvement, only 3 per cent in the non-athlete group had apposing spurs. This seems to indicate definitely that excessive activity must be at least a contributing cause of this condition. Spurring was present in only one bone in 17.5 per cent of the athletes' ankles and in 13 per cent of the non-athletes' ankles.

In order to evaluate the degree of spurring, we defined four classifications: Grade 1, an exostosis which alters the configuration of the bone surface but is small in size; Grade 2, a definite exostosis, the piled mass of bone being sharply delineated; Grade 3, extensive piling up of bone to a height of three-eighths to one-half an inch, the base and tip of the exostosis being discernible; and Grade 4, an exostosis over one-half inch in height with fragmentation or with extension beyond the ordinary site. These divisions are arbitrary and are used to clarify the extent of the process rather than to distinguish between separate entities.

In the group of athletes, forty ankles had Grade 1 spurring, ten had Grade 2 spurring, and four had Grade 3 spurring. In the non-athlete group, sixteen ankles had Grade 1 spurring, only three ankles had either talar or tibial spurring which was graded as high as 2, and none had Grade 3 spurring. On the basis of these figures, it appears that not only is the spurring more frequent in the athlete group but its degree is more severe. Percentagewise, in the athlete group 55 per cent of the ankles had no spurring, 33.3 per cent had Grade 1 spurring, 8.3 per cent had Grade 2 spurring, and 3.3 per cent had Grade 3 spurring. In the non-athlete group 84.2 per cent of the ankles had no spurring, 13.3 per cent had Grade 1 spurring, and only 2.5 per cent had Grade 2 spurring. None had Grade 3 spurring. This is a very decided difference not only in the incidence of exostoses but in the size.

It will be recalled that all of the athletes and non-athletes in this series were students who had reported, not because of any complaint concerning the ankle, but rather because they had been called in for survey. It was hoped that significant findings would result. Each one of these students was asked whether or not he had any complaint in the ankle. No attempt was made to conduct a very detailed examination, and the inquiry referred particularly to pain around the front of the ankle in order to eliminate possible conditions such as flat-foot and arch strain.

Study of Table IV will show that of the fifty-four athletes' ankles in which there was some degree of exostosis, six (11 per cent) had symptoms. On the other hand, of the nineteen non-athletes' ankles with spurring none had any symptoms. This is further evidence that the spurs in the non-athlete group were much less severe than those in the athlete group.

In analyzing the complaints of the athletes, it can be seen that the symptoms were progressively worse in those with the more extensive spurring. This is not statistically significant, but at least it is consistent with the premise that the exostoses were the cause of the pain and that the number and degree of the exostoses magnified the probability of their being symptomatic. Of the six ankles in this group in which there was both spurring and complaint, two had Grade 1 spurring, two had Grade 2 spurring, and two had Grade 3 spurring. It should be noted that this means that 50 per cent of the four ankles with Grade 3 spurring had symptoms, 20 per cent of the ankles with Grade 2 spurring had symptoms, while only 5 per cent of those with Grade 1 spurring had symptoms. Four of the six ankles with symptoms had both talar and tibial spurring, which means that 12.1 per cent of the ankles with apposing exostoses had symptoms.

SUMMARY

I have reported a series of seven athletes (with eight involved ankles) operated upon

TABLE III

ROENTGENOGRAPHIC FINDINGS IN A SURVEY OF THE ANKLES OF 120 ATHLETES AND 120 NON-ATHLETES

Athletes			Non-Athletes		
No exostosis		66 (55%)	No exostosis		101 (84.2%)
Exostoses in only one bone			Exostoses in only one bone		
Talar			Talar		
Grade 1	14		Grade 1	8	
Grade 2	3		Grade 2	1	
	17 (14.2%)			9 (7.5%)	
Tibial			Tibial		
Grade 1	4 (3.3%)		Grade 1	6 (5%)	
		21 (17.5%)			15 (12.5%)
Exostoses in both bones			Exostoses in both bones		
Grade 1	22		Grade 1	2	
Grade 2	7		Grade 2	2	
Grade 3	4				
		33 (27.5%)			4 (3.3%)
Total		120 (100%)	Total		120 (100%)

TABLE IV

COMPLAINTS IN ANKLES WITH EXOSTOSES

Athletes				Non-Athletes			
Location of Exostoses	No. of Ankles	With Complaints (*No.*)	With Complaints (*Per cent*)	Location of Exostoses	No. of Ankles	With Complaints (*No.*)	With Complaints (*Per cent*)
Tibia	4	0	0.0	Tibia	6	0	0.0
Talus	17	2	11.8	Talus	9	0	0.0
Both bones	33	4	12.1	Both bones	4	0	0.0

within a period of five years. The smallness of this series indicates that surgical treatment of this condition is not frequent. In the majority of our cases surgery restored a person who was having increasing trouble to normal activity. This good prognosis is especially important for the athlete since his efficiency is sharply curtailed by the constant lameness which is caused by exostoses.

In the comparative study of the ankles of athletes and non-athletes, the subjects were students of comparable age, all young healthy males. Incidentally, there was no significant difference in findings between those fifteen to twenty years of age and those twenty to twenty-five years of age. We initially divided the subjects into these two age groups but found no statistical differences between them. Whether or not there is some method to prevent impingement exostoses in the athlete or whether or not this condition is of great importance remains to be seen. Certainly, the majority of the athletes in our series, in spite of considerable involvement, were symptom-free. The most important consideration is that when a man presents himself with an indefinite type of complaint regarding the

ankle, it behooves one not to overlook the possibility that his trouble may be from impinging exostoses. I would like to repeat that I think surgery is justifiable as a means of obtaining relief even though the patient may get substantial relief merely by sharply curtailing his activity.

CONCLUSIONS

1. Talotibial exostoses are a definite cause of disability and reduction of efficiency in anyone who has to "drive" hard or forcibly dorsiflex his foot. Once the condition becomes symptomatic, it is likely to be recurrent.

2. Meticulous surgery will result in prevention of recurrence and in permanent elimination of symptoms. In each case reported here, the result was either complete recovery or marked improvement.

3. Talotibial exostoses are frequent findings in young men who have done extensive athletics but are not necessarily symptomatic.

4. The condition is more likely to be symptomatic if there are both tibial and talar spurs since this multiples the danger of impingement.

5. Whenever a good athlete complains of some condition about the ankle which impairs his efficiency, it is important to investigate carefully all facets of his complaint since it is unlikely to be functional.

1. McMurray, T. P.: Footballer's Ankle. J. Bone and Joint Surg., **32-B:** 68–69, Feb. 1950.

DISCUSSION

Dr. Frederick S. Webster, Lincoln, Nebraska: Dr. O'Donoghue has described a rather common lesion caused by trauma in athletes, particularly football players. He has also presented a practical therapeutic approach. This approach has been previously described in the British literature but has generally received little attention.

I have reviewed a series of sixty roentgenograms of a group of varsity athletes seen at the University of Nebraska and have compared them with a series of sixty roentgenograms of students at large who were seen at the Student Health Center because of ankle complaints. Over 50 per cent of the roentgenograms of the athletes in the first group showed evidence of this condition in varying degrees. The roentgenograms in the second group, however, were remarkable for absence of evidence of this condition. The degree of reaction was rather severe in the group of athletes when judged by Dr. O'Donoghue's standards; possibly this was due to the fact that the condition in all of these boys was symptomatic. Through the kind cooperation of the Athletic Department Trainers, Mr. Paul Schneider and Mr. George Sullivan, a clinical evaluation was made of the ankle conditions in this group. In general, the findings were essentially the same as those outlined in Dr. O'Donoghue's paper. The complaints were usually mild in comparison with the severity of the roentgenographic findings. Because of rapid response to rest and immobilization, conservative measures were usually carried out. Most of the athletes who had malleolar changes also had a reaction in the anterior portion of the ankle; however, the great majority of those manifesting this condition had no other changes which could be seen roentgenographically.

[A slide was presented showing a well defined exostosis on the anterior articular margin of the tibia; no changes were apparent over the neck of the talus.] In our series there were several exostoses of this type of varying size. These were treated conservatively, but I would feel that one of this size should be excised.

[In a second slide there was shown the usual picture of reaction with exostoses both along the margin of the tibia and on the dorsolateral aspect of the neck of the talus.] Exostoses of this type definitely increase in size over a period of time if athletic participation continues and may eventually cause rather severe impingement and blocking of dorsiflexion of the foot. It is interesting to note that in a number of high-school athletes, early changes of this nature were evident.

[The third slide showed limitation of dorsiflexion with impingement of two opposed osteochondral masses.] In this case, because of rather marked laxity of the lateral portion of the ankle, reconstruction of the lateral ligament was carried out. The patient continued to have the same complaints, however. These complaints were, of course, due to the findings shown here.

[The fourth slide showed a third type of condition in which there are loose bodies in the joint.] Loose bodies generally result from the development of osteochondral ridges, although they may also form from the synovial membrane. Certainly, in this group operation is indicated.

[The fifth slide showed the ankle of a varsity athlete.] This athlete complained of discomfort in the an-

(*Continued on page 920*)

Epiphyseal Arrest for the Correction of Discrepancies in Length of the Lower Extremities * †

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The problem of asymmetrical growth and the correction of discrepancy in length of the lower extremities is one that the orthopaedic surgeon encounters frequently. In the individual who is still growing, the correction by modification of growth has many advantages provided it can be performed precisely and without complication.

The methods both for stimulation and for inhibition have been the subjects of widespread investigation. The question of stimulation has been particularly challenging since the discrepancy in limb length is more frequently due to shortening, and the contours of the extremities can be better established by lengthening the shortened extremity than by shortening the long extremity. Various methods of stimulating growth have been proposed, but the practical value of these techniques has not been confirmed. The usefulness of inhibition of growth to correct discrepancies, on the other hand, has been better established.

The arrest of growth as a practical procedure was introduced in 1933 by Dallas Phemister in his paper, "Operative Arrestment of Longitudinal Growth of Bones in the Treatment of Deformities". In 1947, the authors reported their experiences in epiphyseal arrest, the technique which was used, and the results, and presented a prediction chart which has been found valuable in the timing of arrests [5]. Two years later, in 1949, Blount reported his findings in the use of staples as a method of inhibiting growth. Our purpose in this paper is to report more recent experiences in epiphyseal arrest, both by epiphyseodesis and by stapling.

In all, our staff has performed 475 operations to correct discrepancy in length of the lower extremities by inhibiting growth; of these, 383 have been epiphyseodeses and ninety-two have been staplings. The patients are all enrolled in our growth study where detailed observations of each are made serially at regular intervals before and after the operation. The records include orthoroentgenographic lengths of the femur and tibia of both extremities, assessments of skeletal age, and anthropometric measurements of the whole child, as well as of the lower extremities. Such observations ordinarily extend over several years before operation and are continued until the growth of the individual is completed. The spacing of these repeated measurements depends upon the age of the child and the interval before and after surgery. Usually observations are made every six months, although measurements of growth in the younger years are performed annually and certain postoperative observations are made as often as every three months.

This report is based primarily upon a study of those patients with epiphyseal arrests who have been observed sufficiently long to permit a final evaluation of the effect of the two types of surgical procedure upon growth. In the instance of epiphyseodesis, the patients were those who had been observed until growth was completed: in all, 237 epiphyseodeses in 173 patients. Another group, with eighty-three epiphyseal staplings **,

* Read in part at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Los Angeles, California, February 3, 1955.

† This study was aided by a grant from The National Foundation for Infantile Paralysis, Inc., New York, N. Y.

** Original figures regarding stapling have been increased by the inclusion of additional cases and evaluations as of November 1956.

FIG. 1-A

Figs. 1-A and 1-B: Case 1. S. W. Photographs and roentgenograms of a boy who showed slow fusion of the distal femoral epiphysis and a severe varus deformity of the proximal end of the tibia following epiphyseodeses; the deformity was ascribed to technical factors in surgery. Bone grafts only were used. Total correction amounted to only 1.9 centimeters instead of the 6.2 centimeters which were predicted at a skeletal age of twelve years, nine months.

Fig. 1-A: Postoperative increase in varus contour of the right knee. The photograph at the left was made before surgery; that at the right was made three years later when the boy was sixteen.

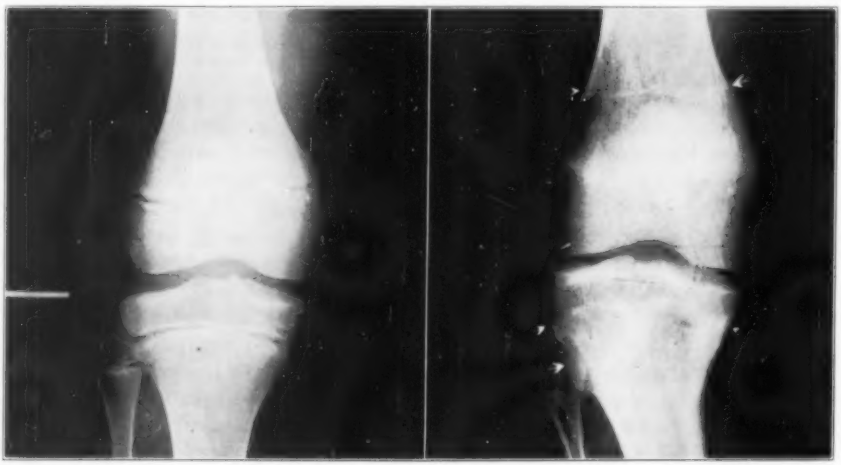

FIG. 1-B

Roentgenograms of the right knee made on the same dates showing the preoperative state and the deformity three years later. The continued growth of 3.0 centimeters at the distal femoral epiphysis and of 2.1 centimeters in the lateral portion of the upper tibial epiphysis are demonstrated by transverse striations laid down in the bones at the time of the surgery.

was made up of those in whom the effect of the procedure had been observed for two years or longer, sixty-one of which were in patients whose growth was completed at the time of last observation. Since the two groups, those with epiphyseodeses and those with staplings,

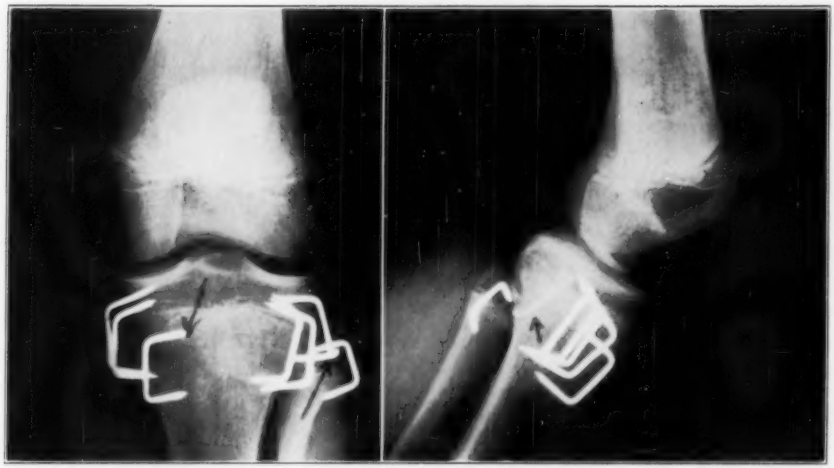

FIG. 2

Case 2. H. R. Roentgenograms of the left knee of a boy made eighteen months after stapling of the upper tibial and fibular epiphyses. Slow arrest resulted, 1.0 centimeter of growth being measured at the operative site. Roentgenograms showed that the staples were in poor position. One tibial staple had completely pulled through the epiphyseal plate, one was extruded and was broken, and the fibular staple was extruding distally. Staples were removed two years after operation and an epiphyseodesis was performed at the same time.

are not comparable, we shall report our experience with each separately instead of making detailed direct comparisons.

The clinical course of the patients after operation in both these groups has been carefully evaluated, and the details of the effects of the surgery upon growth have been thoroughly studied and classified. The performance of the epiphyses following the procedures has been observed at regular intervals on serial roentgenograms, which has permitted the recording of increments of growth during each interval. Deviations from the expected course, either in growth or in clinical performance, were classified as complications. The term *complication* * was used to denote a definitely abnormal clinical course or conditions in which a secondary procedure was either performed or recommended. It is well to point out, however, that a complication did not necessarily indicate that the final result was not good.

EPIPHYSEODESIS

The epiphyseodeses in our series were performed by many different surgeons of our staff and there was considerable variation in the techniques which were used. In general, some modification of the procedure originally described by Dr. Phemister was followed, and the method most frequently employed, which we have described elsewhere, involved the use of bone grafts on either side, thorough drilling of the epiphyseal plate, and packing of the defect thus created in the plate with cancellous bone. There were, however, fourteen arrests in the group in which bone grafts on either side of the epiphysis were used, without otherwise interfering with the plate.

*Asymmetrical fusion was classified as a complication when growth on one aspect of the arrested plate was in excess of five millimeters more than on the other side, resulting eventually in a deformity which was clinically noticeable (Figs. 1-A, 1-B, 3-A, 3-B, and 3-C).

Slow fusion was classified as a complication when eight millimeters of growth or more occurred after the operation or when the first arrest was recognized as not being effective and a second one was required.

Overcorrection of the discrepancies was considered to be significant if it amounted to one-half inch or more, or if arrest of the contralateral side was performed in order to prevent overcorrection.

Neuromuscular dysfunction included all conditions of persistent muscle weakness (there were two patients in this category: one with relative weakness of the anterior tibial muscle, etiology not clear, and another with residual deformity of the big toe, apparently associated with ischaemic changes resulting from compression in a cast).

FIG. 3-A

Figs. 3-A through 3-C: Case 3. C. C. This girl had multiple congenital anomalies of the lumbar spine which resulted in a short left tibia and a deformed left foot; total clinical shortening on the left was one and one-half inches after triple arthrodesis. Femoral stapling, done at a chronological age of ten years and a skeletal age of eleven years and six months, effectively corrected the discrepancy but resulted in clinically significant valgus deformity when the medial staples extruded and did not hold.

Fig. 3-A: The photograph on the left, made before stapling of the right femur and arthrodesis of the left foot, shows the contour of the extremity compared with its appearance (right) three years after these procedures.

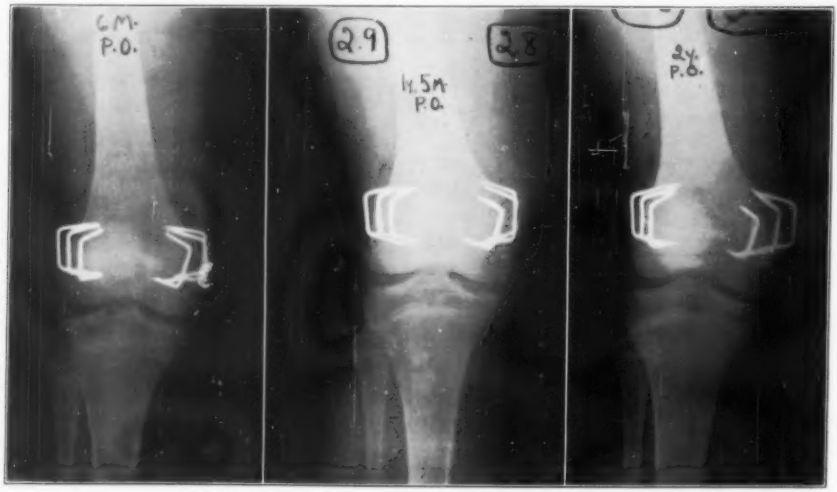

FIG. 3-B

Roentgenograms of the right knee showed progressive extrusion of staples at six, seventeen, and twenty-four months after operation, as well as a lack of spread in one staple which suggested that it, also, was not holding.

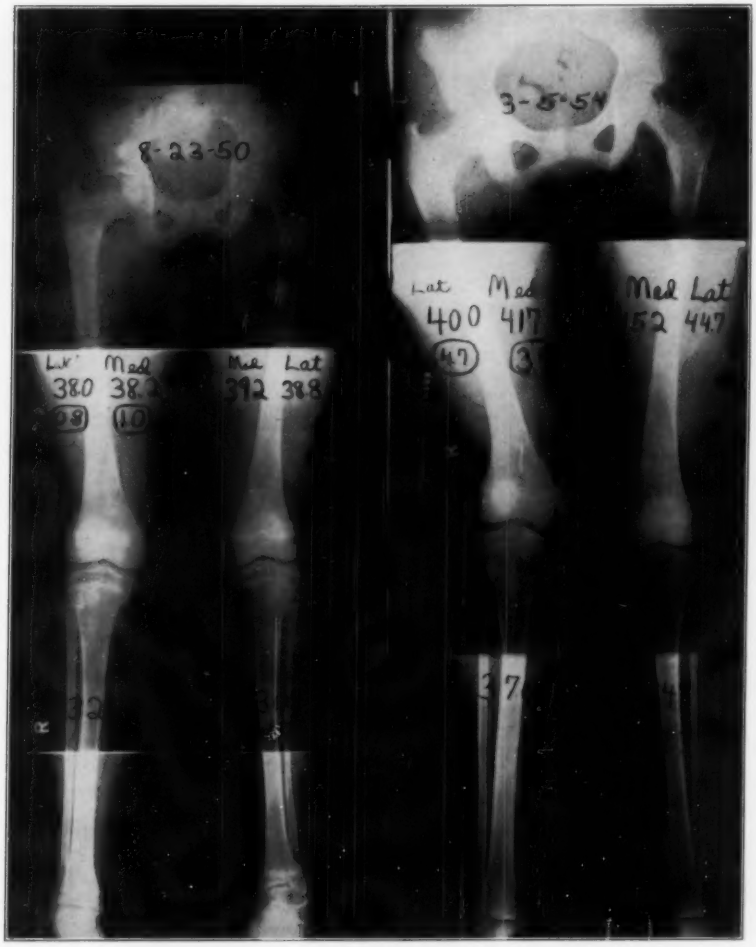

FIG. 3-C

Orthoroentgenogram (right) made seven months after the removal of staples from the right knee shows the extent of the deformity compared with the preoperative orthoroentgenogram (left). Staples had corrected 3.9 centimeters (67 per cent) laterally, but only 2.5 centimeters (43 per cent) medially.

With few exceptions, the final clinical result in the 173 patients with epiphyseodeses was good to excellent. The shortening was well corrected in all but sixteen of the patients in whom the operation was performed to control a rapidly increasing discrepancy rather than to correct it, and in seven patients in whom the procedure was done too late to effect a correction of 1.0 centimeter or more. Overcorrection of the discrepancy was rare; in only two patients of the whole group did the originally shorter limb become as much as one-half inch longer than the other. In five other patients it was thought necessary to perform a femoral arrest on the originally short side in order to prevent what appeared to be imminent overcorrection. There was only one patient in the series who had a residual deformity of consequence, a severe bow-leg. This patient refused to have this corrected by an osteotomy. There were five additional patients with disturbing asymmetrical fusions which warranted a second operation. All of these had straight lower extremities with good correction as a final result, four after osteotomy and one after epiphyseodesis

TABLE I

COMPLICATIONS FOLLOWING 237 EPIPHYSEODESES
A COMPARISON OF TWO SERIES: 1947 AND 1955

	1947		1955		Combined	
	(*No.*)	(*Per cent*)	(*No.*)	(*Per cent*)	(*No.*)	(*Per cent*)
Total procedures	64		173		237	
Asymmetrical fusion	3	4.7	3	1.7	6	2.6
Slow fusion	0	0.0	5	2.9	5	2.1
Infection	2	3.1	0	0.0	2	0.8
Neuromuscular dysfunction	0	0.0	2	1.2	2	0.8
Overcorrection discrepancy	3	4.7	4	2.3	7	3.0
Total complications	8	12.5	14	8.1	22	9.3

was repeated on one aspect of the plate. The amount of correction was close to the predicted amount in most instances, the end result falling within one-half inch of the expected amount in 89.6 per cent of the procedures.

In only two patients the result was classified as totally unsatisfactory, and it was felt that these two patients would have been better off if the procedure had not been done. One was a girl upon whom had been performed one of the early procedures of this series,

TABLE II

COMPLICATIONS FOLLOWING EPIPHYSEODESES
COMPARISON OF THE RESULTS OF TWO OPERATIVE TECHNIQUES

	Grafts and Drilling		Grafts Only	
	(*No.*)	(*Per cent*)	(*No.*)	(*Per cent*)
Total procedures	233		14	
Asymmetrical fusion	3	1.4	3	21.5
Slow fusion	2	0.9	3	21.5
Clinical infection	1	0.4	1	7.1
Neuromuscular dysfunction	2	0.9	0	0.0
Overcorrection discrepancy	6	2.7	1	7.1
Total significant complications	14	6.3	8	57.2

reported in 1947. Unfortunately, postoperative infection and osteomyelitis developed which drained for some time although no secondary operation was necessary. She had no residuum of infection, but none of her limb-length discrepancy was corrected; actually, it was increased one millimeter. The other patient with a poor result was a child in whom only 0.7 centimeter of correction was obtained. A circular plaster splint had been applied to this child's limb which caused pressure necrosis on the back of her calf, associated with a temporary neuromuscular difficulty and a residual cock-up deformity of her large toe, probably the result of ischaemia.

Incidence of Complications

In this group of epiphyseodeses there were twenty-two (9.3 per cent) postoperative difficulties which were considered significant (Table I). The incidence of complications reported in our earlier series [5] was ten in seventy-seven * procedures (13.0 per cent).

* Of these, thirteen were not included in the present series since the operations had been done elsewhere and sufficient records of the operative procedures were not available for analysis.

Among the 173 arrests performed more recently the incidence of complications was found to be definitely less, namely, 8.1 per cent. It was further found that one-third of the so-called complications in the new series were classified as slow fusion, which might not be considered a complication at all in the ordinary sense of the word, since the term merely indicates that the epiphyseodesis was not as effective in stopping growth as had been anticipated.

Cases in which the postoperative fusion of the epiphysis was either slow or asymmetrical, resulting in deformity, were studied as to the cause of the irregular fusion. In all instances where analysis was possible, the disturbance was ascribed to technical factors in the procedure. This was emphasized when the data were further compared by considering separately those arrests in which grafts alone were used, without either drilling or curettage of the plate. The results of the fourteen arrests in this category were compared with the results in 223 procedures of the usual type (Table II). There may well be other factors entering into these comparisons, but the fact that three of the fourteen patients had asymmetrical fusion and another three had slow fusion is pertinent and suggests that the combination of bone-grafting, drilling, curettage, and packing is to be preferred to the use of bone grafts alone (Figs. 1-A and 1-B).

Following the 237 epiphyseodeses, nineteen secondary operative procedures were either performed or recommended, giving an incidence of 8.0 per cent for the whole series (Table VI). The incidence of secondary procedures was less in recent cases than in the earlier series reported in 1947. Of the nineteen patients who needed secondary procedures, four had osteotomies to correct deformities. There was one other patient with deformity in whom an osteotomy was recommended but he preferred not to have it (Figs. 1-A and 1-B). In five patients, arrests were performed on the originally shorter limb to prevent overcorrection, and in six other patients the epiphyseodesis was repeated on one or both sides of the epiphysis when there was evidence that the first procedure was not proving effective. These three groups included sixteen of the nineteen patients who required secondary operative procedures. The final clinical results in patients who had secondary operations were recorded as good to excellent.

Prediction

The use of epiphyseodesis as a practical procedure depends largely upon a reasonable accuracy in the prediction of growth in order to determine at what age the operation should be performed. The chart of prediction which we presented in 1947 [5] has been used at The Children's Medical Center and has proved to be a highly desirable guide. The 1951 revision [6], although founded upon more and improved basic data, shows averages which are so similar to the original figures that we have continued to use the earlier chart. Occasional reports of failure to gain the expected correction using this prediction chart [4] led us to a thorough re-evaluation of the results obtained in our patients. There were 125 patients whose arrests had all the requisites necessary to evaluate the effectiveness of our predictions *.

We have previously emphasized the importance of the use of skeletal age in prediction. The original chart was developed using the Todd Atlas for estimating skeletal maturation. At present the Todd Atlas is out of print and it has been supplanted by the Greulich-Pyle Atlas. The actual corrections obtained from our arrests were, therefore, compared with the predicted amounts of correction based upon skeletal-age estimates from each of the two atlases. When the skeletal age as interpreted by the Todd Atlas was used

* In order to qualify for this group, it was necessary that roentgenograms of the patient's hands and wrists, as well as orthoroentgenograms, had been made prior to arrest, that these roentgenograms were available for re-evaluation, and that serial orthoroentgenograms and roentgenograms for skeletal age assessment, made at regular intervals, were available throughout the period of growth until maturity. In addition, of course, it was necessary that all the epiphyses on the side opposite to the arrest had contributed to growth in an essentially normal fashion.

TABLE III

CORRECTION VERSUS PREDICTION IN 125 EPIPHYSEODESES
DISTRIBUTION OF RESULTS USING TWO SKELETAL-AGE STANDARDS

	Range (*Centimeters*)	Femur (48)		Tibia (77)	
		Todd (*Per Cent*)	Greulich-Pyle (*Per Cent*)	Todd (*Per Cent*)	Greulich-Pyle (*Per Cent*)
Correction more than prediction	2.5–3.0	4.2	2.1	0.0	0.0
	1.9–2.4	2.1	4.2	0.0	0.0
	1.3–1.8	4.2	2.1	2.6	1.3
	0.7–1.2	12.5	8.3	6.5	3.9
	0.0–0.6	35.4	16.7	19.5	16.9
Correction less than prediction	0.0–0.6	22.9	41.7	36.4	37.7
	0.7–1.2	14.6	22.9	26.0	31.2
	1.3–1.8	4.2	2.1	2.6	3.9
	1.9–2.4	0.0	0.0	6.5	5.2
	2.5–3.0	0.0	0.0	0.0	0.0

Correction within one-half inch of prediction:
89.6 per cent (Greulich-Pyle); 88.3 per cent (Todd)

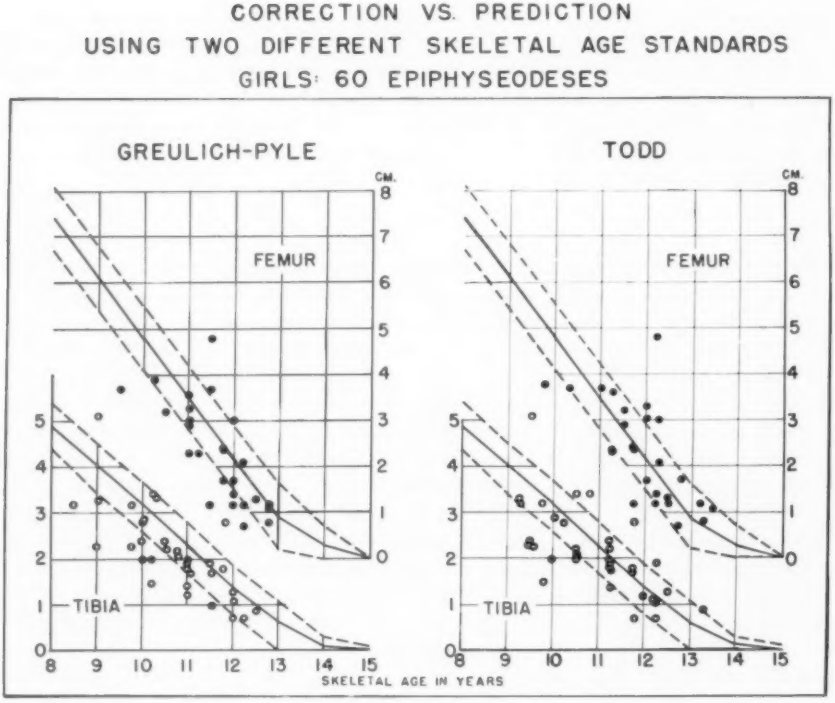

CHART I-A

Charts I-A and I-B: The results obtained following epiphyseodeses are essentially the same, using either standard for skeletal-age evaluation at the time of operation. Distributions of 125 final corrections are shown graphically on the prediction chart of 1947, plotted according to each individual's skeletal age assessed with the Greulich-Pyle Atlas and with the Todd Atlas.

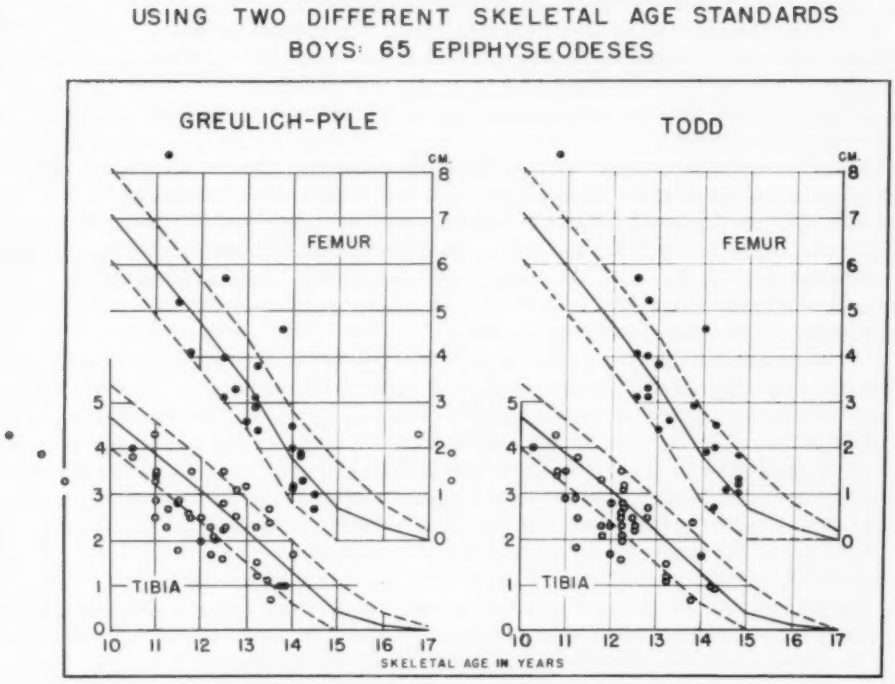

CHART I-B

in prediction, the correction in the group of 125 epiphyseodeses was within one-half inch of the prediction in 88.3 per cent of the procedures; when the Greulich-Pyle Atlas was used, 89.6 per cent were within this range, an essentially identical figure for the two methods (Table III). There were, however, certain differences between the two standards which were discernible on closer examination despite the fact that these two percentages are very similar. The skeletal age for a particular child as evaluated from roentgenograms by means of the Greulich-Pyle standard tends to be a little younger than the skeletal age as interpreted from the same roentgenograms by use of the Todd Atlas. This was particularly evident in girls between the ages of eleven and twelve years. This difference in estimation of skeletal age may be seen if our results from epiphyseal arrest are considered in relation to the original table of prediction, using first one standard and then the other (Charts I-A and I-B). Less correction than the average predicted amount was obtained more often when the Greulich-Pyle Atlas was used for estimating skeletal age.

The effect of the two skeletal-age standards upon predictions may be further appreciated by comparison of the distributions of the 125 actual corrections obtained with the average amounts predicted (Table III). With either method of skeletal-age evaluation, an essentially similar proportion of the results fell within 1.2 centimeters of the predicted amount; yet, when the Greulich-Pyle Atlas was used, the relative number in whom less than the average correction was obtained was increased. The actual differences in amounts of correction predicted with use of the two atlases, however, were so small that these two standards may be used interchangeably. Further experience with the new Greulich-Pyle Atlas, to be published in 1957, may lead to minor changes in the prediction chart.

The reasons for failure to achieve predicted results were sought with care. Detailed

findings cannot be reported here, but they fall roughly into four categories: (1) failure of the bone opposite the arrest to contribute its expected growth; (2) failure of the procedure upon the epiphysis to effectively stop growth; (3) difficulties arising in judgment of skeletal age and in the changing patterns of maturation in the individual child; and (4) the relative size of the individual.

The failure of the bone opposite the side of the arrest to contribute normal growth after the operation was seen most often in the tibia, where, in such conditions as poliomyelitis, the distal tibial epiphysis on the shorter side often contributed less to growth than the distal tibial epiphysis on the normal side. Under these circumstances, the correction achieved from the arrest was less than that expected by the amount which the distal tibial epiphysis on the longer side operated upon exceeded that of the corresponding epiphysis on the shorter side. One constantly must consider that any amount of correction obtained depends upon the effectiveness of growth on the shorter side after the epiphysis is ablated on the longer side.

The importance of growth on the shorter side and the difficulties which may arise because of the failure of an epiphyseodesis to correct the amount predicted was further appreciated by studying the relative growth of each epiphysis after arrest. This was done by measuring the transverse lines which were laid down at the time of operation at the growing ends of each bone. When the actual correction in over-all bone length of the tibiae, as measured from the orthoroentgenograms, was compared with the average amount predicted, the two agreed fairly well, but the majority of corrections (73 per cent) fell a little below the prediction. When the actual growth at the upper tibial epiphysis not operated upon was measured from these transverse lines, however, this growth was found to be much closer to the predicted correction—52 per cent being slightly above and 48 per cent being below the expected amount. Furthermore, when the amounts of growth at the distal epiphyses of the two tibiae were measured in this manner, it was usually found that the correction obtained in over-all tibial length was less than the predicted figure by an amount equal to the inhibition of growth of the distal tibial epiphysis in the shorter limb.

On rare occasions, the surgery itself may not result in an effective arrest of growth, so that less correction is obtained than predicted. The average growth at the site of arrest after epiphyseodesis in our patients was 0.13 centimeter in the tibia and 0.05 centimeter in the femur. Such slight postoperative growth in our series was of little consequence in upsetting predictions. In staplings, some growth after the procedure does occur at the arrested epiphysis, and the result, therefore, may be less than the predicted amount of correction; the average growth after stapling in this series, however, was still relatively little, amounting to 0.60 centimeter.

The third and most difficult factor in prediction is the interpretation of skeletal maturity. Regardless of which atlas is used for evaluations, changes in skeletal age in relation to a child's chronological age may occur as the child matures. The greatest difficulty arises when an individual child shows a tendency toward slower or more rapid skeletal maturation during adolescence after an arrest has been performed. For example, on occasion a child whose skeletal age has been *average* may, in a short period, show a marked acceleration of maturity with a corresponding advance in skeletal age and with earlier fusion of all his epiphyses commensurate with such acceleration. He will therefore not gain as much from an arrest as would a child who had matured more gradually. On the other hand, a child with accelerated skeletal age may shift later so that he has an average skeletal age, with the result that, if the prediction were made on the basis of the accelerated skeletal age and an arrest was performed accordingly, more correction would be obtained than was predicted.

The children whose skeletal ages differ most from their chronological ages often present the greatest problem. It may be said that if a child is as much as two years advanced

or retarded in skeletal age in relation to his chronological age, there is a tendency for his skeletal age to shift toward the average and this fact should be considered when predictions are made for an individual child.

Maturation is an individual process, and a great advantage arises when the patient is observed for an interval before the prediction must be made.

Still another factor is the relative size of the individual. All other things being equal, such as the preoperative rate of growth inhibition, a tall child who grows a great deal during the period following arrest should receive a greater correction than a short individual; actually, this is of less consequence than it appears, although it must be considered. When the fourteen tallest patients and the twenty shortest patients of this series were selected and the effects of their arrests compared, the taller children were found to have obtained only slightly greater correction than the shorter children. To investigate this problem further, a longitudinal series of seventy boys and seventy-four girls who had had no epiphyseal arrests were divided into three groups according to the lengths of their femora and their tibiae at maturity. The cumulative growth of the long bones in the years before epiphyseal fusion was derived for each group; the average growths, as well as the growth ranges, were found to be almost identical for those with long, with medium, or with short bones. During the last five years of growth, for example, the total increment of growth of the shortest femur, 38.9 centimeters at maturity, and the longest femur, 51.4 centimeters, differed by only 1.3 centimeters. This means that there would have been no great difference in these two individuals in the amount of correction obtained from a femoral arrest performed five years before epiphyseal fusion.

For the present, the prediction chart based on either the Greulich-Pyle skeletal ages or the Todd skeletal ages is an excellent working guide to prediction, but various factors must be considered when it is used. The possibility has been considered of using coefficients to modify the predictions, based upon such factors as inhibition of growth in the shorter limb and the height of the individual. Although all these aspects enter into prediction and must be considered, particularly the evidence of inhibited growth on the shorter side, no definite correction factor is proposed since other variables—operative technique, for example—may affect the prediction even more. In estimating the future growth of a child, few things are more important than knowledge of his past growth. Serial, preoperative records of the relative growth occurring on the two sides, of the roentgenographic appearance of the epiphyses themselves, as well as serial evaluations of skeletal maturity, are of inestimable value in figuring both the correction to be derived from a specific epiphyseodesis and the pattern of maturation which the child will be most likely to follow.

STAPLING

Stapling of the epiphyseal lines as a method of correcting discrepancies in limb length has been in use at The Children's Medical Center since 1949. Observations have been made on eighty-three such procedures for two to six years following operation, and during this interval, growth of the lower extremities has been completed in sixty-one of the children involved. The material for the present evaluation is derived from sixty-six femoral and seventeen tibiofibular staplings.

Ordinarily, in staplings of the femur or of the tibia, three stainless-steel staples were used to straddle the epiphyseal line on either side of the plate, distributed evenly on the medial and lateral surfaces. In one patient, four small staples were used on either side of the proximal epiphysis of the tibia; in another patient four large staples were inserted in the medial aspect of the distal femoral epiphysis to correct a valgus deformity, and a year later three large staples were added on the lateral aspect to correct the over-all discrepancy in length. In stapling the fibula, two staples, introduced on the lateral side, were used in eleven patients; in five others one staple only was used; and in one patient a fibular epiphyseodesis was performed in conjunction with the stapling of the tibia.

TABLE IV

MEAN PER CENT * OF CORRECTION AFTER EPIPHYSEODESIS OR STAPLING

	First Six months	Second Six months	Years after Operation First	Second	Third
Femur					
Epiphyseodesis (57)	55	68	61	69	70
Stapling (54)	44	58	51	66	66
Tibia					
Epiphyseodesis (91)	45	45	45	46	47
Stapling (13)	36	38	37	44	49

* Computed as correction (in centimeters) divided by amount of growth of opposite bone during interval.

The staples were placed extraperiosteally in all but ten patients. In forty-seven procedures, the staples were placed without disturbing the periosteum, the plate being tentatively located visually and by palpation, its position confirmed by the use of cambric needles with roentgenographic visualization. In nineteen instances, a short incision in the periosteum was used to locate the plate and then the staples were placed extraperiosteally. In the seven remaining procedures, the details of the operative notes were not clear. Ordinarily, the staples were placed tentatively, checked by roentgenogram, and then driven home.

In this series, stapling was found to inhibit growth effectively. It did permit an average postoperative growth of 0.6 centimeter at the stapled epiphysis, however, which meant that the procedure was somewhat less immediately effective than epiphyseodesis. If the definition for slow arrest, previously described, is applied to these results at two years after operation, as many as 13 per cent showed significant slow fusion of the epiphyseal line. This continued growth at the operative site was observed principally during the first year after surgery. The percentage of the growth of the bone which was inhibited

TABLE V

OPERATIVE RESULTS FOLLOWING EPIPHYSEAL STAPLINGS

	Femoral	Tibio-fibular	Total (*No.*)	Total (*Per Cent*)
Total original procedures	66	17	83	100.0
Effective arrests without complicating factors	51	4	55	66.2
Arrests with complications affecting correction:			13	15.7
(a) Asymmetrical growth	2	0		
(b) Slow arrest *	6	5		
Arrests with complications affecting staples only	6	7	13	15.7
Wound infection	1	1	2	2.4
	Femur	**Tibia**	**Fibula**	**Total**
Total staples inserted	393	105	27	525
Broken	1	4	2	7
Carried across line	0	2	0	2
Extruded: completely	1	4	0	5
partly	8	4	7	19
Replaced (poor position)	0	1	0	1
Removed (surrounding infection)	0	1	0	1
Total staples with complications	10	16	9	35

* Postoperative growth at stapled epiphysis 0.8 centimeter or more.

TABLE VI

SECONDARY OPERATIVE PROCEDURES FOLLOWING EPIPHYSEODESES AND STAPLINGS

	Epiphyseodeses		Staplings	
	Femur	Tibia	Femur	Tibia
Total original procedures	104	133	66	17
Correction of deformity (osteotomy)	1	4	1*	0
Control of overcorrection:				
Epiphyseodesis on opposite side	5	0	0	0
Removal of staples	0	0	4	0
Correction of technical faults:				
Secondary epiphyseodesis	2	4	0	1*
Repositioning of staples	0	0	1	3
Procedures for infections	0	2	0	1
Removal of all staples	0	0	5	5
Miscellaneous (deformity of toe)	1	0	0	0
Total secondary procedures	9	10	11	10
Incidence	8.0 per cent		25.3 per cent	

* In these two patients, all staples were also removed.

by staplings rose appreciably as time went on; in the femur, for example, it increased from 44 per cent during the first six months to 66 per cent during the second and third years (Table IV). By the second postoperative year, the percentages of correction obtained were very similar, whether an epiphyseodesis or an epiphyseal stapling had been performed—69 per cent compared with 66 per cent in the femur, and 46 per cent compared with 44 per cent in the tibia.

Almost all staples were observed to spread to a greater or lesser degree in these patients with some spreading as much as 1.5 centimeters. Most of this increase in distance between the points of the staple occurred, as might be expected, during the first year after insertion. The degree of spread did not seem to be related either to the size of the staple or to the rate of growth of the contralateral bone, nor could we see that the position of the staple in relation to the epiphyseal line was a factor. The construction of the staple itself was probably of the most importance in this regard.

The incidence of complications following stapling was greater than following epiphyseodesis among the patients of this series, but these complications were usually of no great consequence (Table V). There were two instances of asymmetrical growth and eleven instances of slow arrest with growth amounting to eight millimeters or more after stapling. In fourteen procedures, one or more staples were found to be in difficulty. One staple was surrounded with infection and had to be removed, and five others were either removed or replaced because they were completely extruded from the bone. Nineteen other staples showed incomplete extrusion as judged from roentgenograms. Eight of these were eventually removed, but the others held satisfactorily. In two staples, the tine which originally had been placed in the ossification center of the epiphysis was carried across the epiphyseal line into the diaphysis, but deformity resulted in neither instance. In fifteen other cases which are not included in Table V, the tines of the staples which were in the epiphysis moved toward the plate but not into the shaft. An additional seven staples in five patients became broken and in three instances were surgically removed. In all, thirty-five of the 525 separate staples upon which these observations are based were found to be in some demonstrable difficulty, but fourteen of these still remain *in situ*, causing no symptoms.

Not included among the complications in Table V were fourteen other staples which were inserted with the tines directed posteriorly in such a way that the points penetrated

TABLE VII
REASONS FOR REMOVAL OF ALL STAPLES
IN FOURTEEN OF EIGHTY-THREE PROCEDURES

	Femur	Tibia and Fibula
Total original procedures	66	17
Growth complete (five patients):		
No complaints	1	0
Some discomfort	2	2
Growth incomplete (nine patients):		
To allow resumption of growth	4	0
Broken staple	0	1
Loose staple	1	0
Extruded, broken staples; pain	0	2
Extruded staples; deformity, pain	1	0
Total with removal	9	5

the cortex and emerged a few millimeters beyond the posterior surface of the bone. It is worthy of comment that this occurred in 17 per cent of the procedures. In the majority of these instances, new bone was seen to build up around these points, but in several no such osseous change was noted in the roentgenograms.

There was a high incidence of secondary operations following stapling. Such secondary procedures were more often necessary following staplings of the upper epiphyses of the tibia and the fibula than when the lower epiphysis of the femur was stapled (Table VI). The most common of these procedures was the removal of all staples; this was performed in five of the seventeen patients who had tibiofibular arrests (29 per cent) and in nine of the sixty-six patients following femoral staplings (14 per cent)*. Furthermore, in one instance of tibiofibular stapling it was considered desirable, because of unsatisfactory technical factors, to remove the staples and to perform an epiphyseodesis (Fig. 2). There were also three patients among the seventeen with tibial staplings who required repositioning of one or more staples. In contrast to this, only two instances of technical difficulty were found among the sixty-six femoral staplings (Table VI). Because of the technical problems and the high incidence of complications which arose from tibial stapling, stapling of the tibia has been frowned upon recently, and no stapling of the upper tibial and fibular

* In six of the fourteen patients in whom all staples were removed, the procedure might be classified as elective, but in the other eight patients there was real indication for removal.

TABLE VIII
GROWTH IN LENGTH OF LONG BONES FOLLOWING REMOVAL OF STAPLES

Months *in situ*	Patient Name	Sex	Skeletal Age *	After Removal of Staples: Duration of Observation (*Mos.*)	Bone Growth Operated (*Centimeters*)	Bone Growth Unoperated (*Centimeters*)	Present Status of Epiphyses Unoperated Upon
Equal growth after removal:							
22	K. J.	F	12 yrs., 6 mos.	34	2.3	2.3	Closed
18	H.R.	M	14 yrs., 9 mos.	34	2.1	2.0	Closed
35	C.C.	F	15 yrs., 3 mos.	13	0.1	0.2	Closed
Continued correction after removal:							
25	P.C.	M	14 yrs., 0 mos.	30	1.5	2.6	Closed
19	W.L.	M	15 yrs., 3 mos.	16	0.3	1.2	Very narrow
24	C.N.	F	13 yrs., 3 mos.	11	0.2	0.6	Narrow

* At the time staples were removed.

epiphyses to correct discrepancy in limb lengths has been performed at The Children's Medical Center since October 1954.

No separate tabulation was made of the performance of the fibular epiphysis, but it may be commented that of the twenty-seven staples which were inserted into the fibulae of the patients in this series, seven were partially extruded and two broke with separation of the fragments. It was common, when staples were introduced on the lateral side of the fibula, for growth to be inhibited on this side and to continue on the medial side with distortion of the head of the fibula; the distortion was considerable in three patients. This deformity, however, was not a complication of clinical significance in any of our arrests.

Despite the apparent high rate of complications and secondary operations following staplings, there was only one complication of significance:

CASE 3. C. C., a girl, had a femoral stapling performed when she was ten years old when her skeletal age was eleven years and six months. She had little or no deformity for seventeen months. At that time the roentgenograms showed that two staples on the medial side were backing out, one to a small extent and the other to a considerable degree. Nothing was done to correct this, and seven months later a well developed genu valgum was present.

All staples were removed thirty-five months after their insertion. When this was done, those on the lateral side were found to be firmly implanted, but those on the medial side were not holding. One of the medial staples was lifted out without any resistance, and only the posterior staple was holding firmly with both prongs. Little growth was observed after removal, the deformity remained, and an osteotomy was recommended (Figs. 3-A, 3-B, and 3-C).

This was the only patient in whom the present result is other than good.

Comments on Removal of Staples

It was our policy usually to use staples as an alternate technique for epiphyseodesis rather than as a procedure intended to temporarily inhibit growth. Since the staplings were used in this way, we have had few instances of the staples being removed to allow growth to resume (Table VII). All staples were removed from fourteen patients, five after growth was completed and nine before growth had terminated. In six of the latter patients, sufficient time had elapsed to enable us to observe the growth in the two sides after removal of the staples. In three of these patients, growth was essentially the same on the stapled side as on the side not operated upon; in the other three, however, less growth occurred on the side from which the staples had been removed (Table VIII).

The vagaries of growth which may occur after the removal of staples and the possible difficulties which may arise from dependence upon the resumption of growth are well illustrated by comparing two patients. In both, a distal femoral stapling was performed at the same time that an epiphyseodesis of the upper tibial and fibular epiphyses was done, and the staples were removed less than two years after insertion in order to allow growth to resume.

CASE 4. K. J., a girl twelve years old, presented congenital hypertrophy with a total discrepancy of 4.7 centimeters in one of her lower extremities—2.4 centimeters in the femur and 2.3 centimeters in the tibia. The average predicted effect from arrest at her assessed skeletal age of ten and one-half years was 2.7 centimeters in the tibia and 4.2 centimeters in the femur.

Her skeletal age was retarded for her chronological age and showed irregularities which made exact prediction difficult. It seemed wise, therefore, to do a tibial epiphyseodesis combined with a femoral stapling with the idea that the tibial procedure would give a permanent arrest which could continue throughout her growth period and that the staples could be removed if it were indicated in order to permit growth to resume.

Both procedures were effective; twenty-two months after operation the tibial discrepancy was reduced to 1.0 centimeter and the femoral discrepancy to 0.7 centimeter. The patient was then fourteen years old with a skeletal age of twelve and a half years, and, accordingly, the staples were removed. Her femur resumed growth paralleling the growth on the other side. The correction of the tibia continued, so that at a skeletal age of thirteen years and nine months the tibia was within one millimeter of the other side and the femur which had been operated upon was still nine millimeters longer than the other side. After removal of the staples, the growth of the previously stapled femur was 2.1 centimeters, as compared with 1.9 centimeters on the side not operated upon (Fig. 4).

CASE 5. W. L., a boy with a spina bifida, had fairly severe scolosis which was aggravated by a discrep-

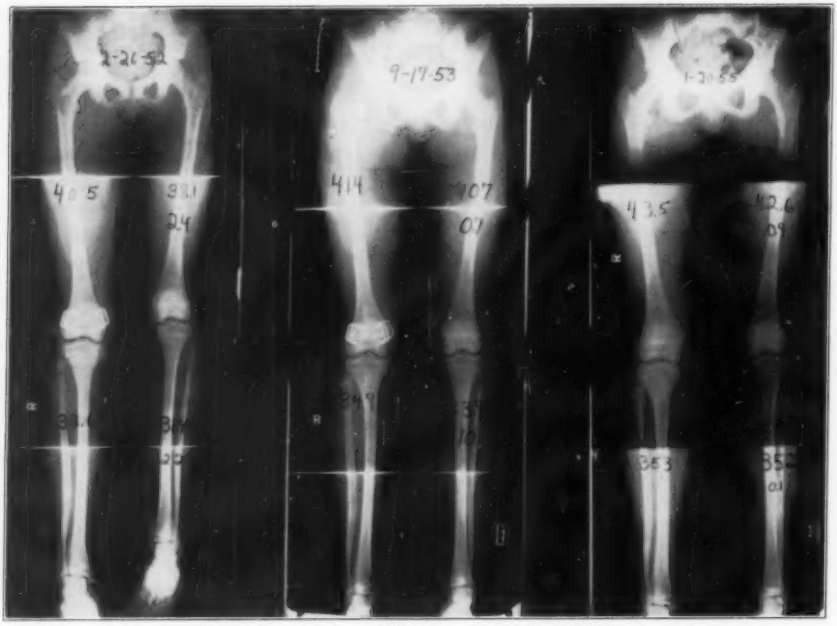

FIG. 4

Case 4. K. J. Orthoroentgenograms of a girl in whom normal growth resumed following the removal of staples. Left: three months after stapling of the distal femoral epiphysis and epiphyseodesis of the proximal tibial and fibular epiphyses to correct a total discrepancy of 4.7 centimeters. The patient's skeletal age was ten years, nine months. Center: twenty-two months later the total discrepancy had been reduced to 1.7 centimeters. The patient's skeletal age was twelve and a half years; her chronological age was fourteen years. The staples were removed at this time. Right: sixteen months after the staples were removed. The two femora had grown an equal amount, 2.1 centimeters on the stapled side and 1.9 centimeters on the opposite side. Tibial correction was 2.2 centimeters (55 per cent) in the thirty-eight months since the arrests were done.

ancy in limb length of 2.2 centimeters, divided equally between the femur (1.2 centimeters) and the tibia (1.0 centimeter). A raise of approximately four centimeters was required under his left foot to balance his back. His skeletal age had consistently been one year in advance of his chronological age, and at the time of operation it was thirteen years and nine months.

In the first eighteen months after the arrests, rapid correction was obtained from epiphyseodesis of the upper tibial and fibular epiphyses (1.6 centimeters or 53 per cent), actually more than was gained from the stapling of the distal femoral epiphysis (1.3 centimeters or 41 per cent). At that time his back was much better balanced and it was decided that further inhibition from the femoral arrest was not needed, so the staples were removed.

Growth at the stapled distal femoral epiphysis did not resume, and a continued "correction" of 0.9 centimeter was observed in the next seventeen months. The discrepancy is now overcorrected by 1.8 centimeters (Fig. 5).

In both these patients, the staples were placed extraperiosteally with minimal difficulty in positioning, and in both patients the staples were removed easily without undue trauma. The two children were both in the active phase of growth when the staples were inserted; the epiphyseal lines in both patients were wide at the time of arrest, and those of the normal side not operated upon were still patent at the time the staples were removed. Roentgenograms of the stapled epiphyseal plates, however, appeared very different in the two patients. In the girl (Case 4), the epiphyseal line was narrow although clearly seen in roentgenograms made the day before the staples were removed; in the boy (Case 5), however, the epiphyseal line showed much greater narrowing and had almost disappeared according to the roentgenogram made eighteen months after insertion of the staples. In the girl, growth was resumed and continued at the same rate on the two sides,

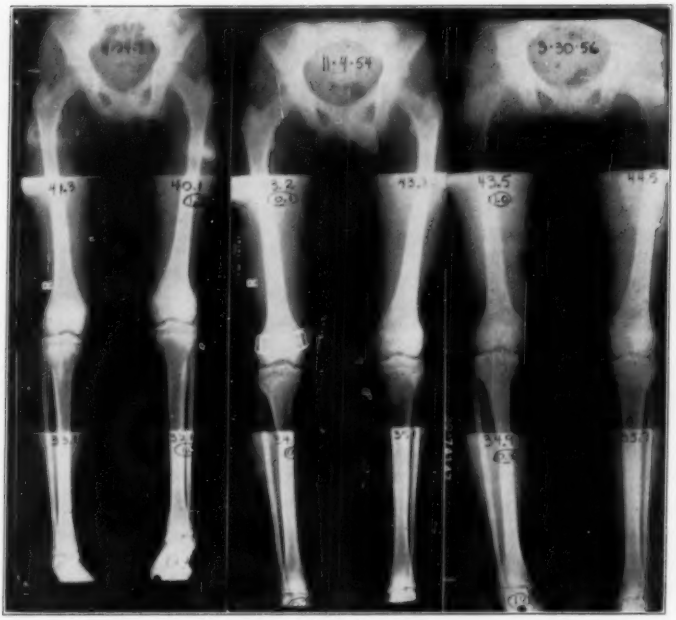

FIG. 5

Case 5. W. L. Serial orthoroentgenograms showed little resumption of growth after removal of staples in this boy. Left: a preoperative discrepancy of 2.2 centimeters in bone length is shown, although well over an inch was needed to balance this boy's back. His skeletal age was thirteen years, nine months; his chronological age was twelve years, nine months. Center: eighteen months after epiphyseodesis of the right proximal tibial and fibular epiphyses and stapling of the right distal femoral epiphysis, the right limb was 0.7 centimeter shorter than the left, and the boy's scoliosis was much better balanced. Staples were removed one month later, at a skeletal age of fifteen years, three months. Right: seventeen months after the staples had been removed, the right femur had grown only 0.3 centimeter while the left had increased 1.2 centimeters, a continued inhibition of 80 per cent in the right femur. The total correction in tibial lengths had amounted to 1.8 centimeters (50 per cent).

but in the boy resumption of growth did not occur following removal of the staples although the opposite side continued to grow. Basically, these two procedures were technically as similar as could be; yet one femur grew after removal of staples and the other did not.

In an attempt to observe further the effect of stapling on the epiphyseal plate and, indirectly, to obtain further information about the potentialities of growth after removal of staples, the roentgenographic appearance of paired stapled and unstapled plates was reviewed. In fifty-three patients of this series from whom the staples had not been removed, there were available serial roentgenograms of both knees which had been made before operation and throughout the growing period until growth was completed in both extremities. In this group, the younger the skeletal age of the child at the time when stapling was performed, the longer was the length of time during which the plate remained visible; in one patient the stapled epiphyseal line remained roentgenographically identifiable for four years. On the other hand, all of the plates which had been stapled became obliterated —as judged from the roentgenograms—before the comparable plates on the side not operated upon showed the same appearance. This roentgenographic disappearance of the epiphyseal plates occurred at an average of one year earlier in the plates stapled than was seen in the contralateral bones not operated upon, with the recorded range in this precedence extending from four months to two years. In six (11 per cent) of these patients, for

TABLE IX

CORRECTION VERSUS PREDICTION
COMPARISON OF RESULTS IN EPIPHYSEODESES AND IN STAPLINGS
(Skeletal Age Assessed with the Greulich-Pyle Atlas)

	Epiphyseodeses		Staplings	
	(*No.*)	(*Per cent*)	(*No.*)	(*Per cent*)
Total procedures for evaluation	125	100.0	44	100.0
Correction within 0.25 inch of prediction	70	56.0	25	56.8
Correction within 0.50 inch of prediction	112	89.6	39	88.6
Correction more than 0.50 inch above prediction	5	4.0	0	0.0
Correction more than 0.50 inch below prediction	8	6.4	5	11.4

example, the stapled epiphyses appeared to be obliterated eighteen months, or more, before the unstapled epiphyses disappeared. One cannot be sure by roentgenographic interpretation about the actual state of the epiphysis and its growth potential, especially when stapling has modified the appearance of the plate. Information is greatly needed as to the potentialities of growth which exist in relation to the roentgenographic changes occurring at the epiphyseal plate following stapling. This knowledge can be obtained only by roentgenographic serial study of a large series of epiphyses, before and after removal of the staples. In this way, the various changes in the epiphysis can be correlated with the growth which occurs after removal.

In our series the reaction of the bone and soft tissue to the presence of staples, as seen at operation for their removal, was varied. In all, ninety-six staples were removed from nineteen individuals. Half of these staples were found to be firmly seated; they were located with little or no difficulty and no particular reaction of bone or soft tissue was observed at the time the staples were explored. In several patients, thick, fibrous, oedematous tissue or a membranous bursal sac was found covering the top of the staple. Among fifty-six staples which were known to have been inserted extraperiosteally, either with or without an identifying incision of the periosteum, fourteen (25 per cent) were found to lie subperiosteally or actually under a layer of bone. In two patients in whom subperiosteal stapling had been done, the staples were found to be deeply buried in bone; as much as 1.5 centimeters of bone had to be removed with an osteotome in order to visualize one of these staples. In another patient, however, in whom the staples had also been inserted subperiosteally, one staple was found to be completely free of bone, lying in subcutaneous tissue. Difficulty was encountered in extracting the staples from two of the nineteen patients, while in the others the staples were located and removed with comparative ease.

COMMENTS AND COMPARISONS

Epiphyseodesis and stapling are both effective procedures for correcting limb-length discrepancy provided they are used correctly (Table IX). In our series, both procedures have inhibited similar percentages of growth after the first year, although during the first postoperative year stapling was somewhat less effective. There was a high incidence of complicating factors in our cases, but generally these complications were minor and the final result was good, even in the few patients in whom a secondary operative procedure was necessary.

Epiphyseodesis and stapling each has its advantages and its disadvantages. Epiphyseodesis is a particularly satisfying operation to do. It is a direct and definitive procedure; the technical details are appealing and can be well controlled. It is clean-cut and final. Its weakness, however, is that its status as a procedure of choice often depends upon the accuracy of prediction, which, on occasion, may present problems. In this series, however, remarkably few difficulties have arisen in epiphyseodeses from errors in prediction.

Overcorrection, which is one of the most disturbing complications that may arise after an arrest, rarely occurred. Epiphyseodesis, however, is a final thing, and if prediction has gone awry and overcorrection is threatened, the only recourse is to fuse an epiphysis in the patient's originally shorter limb. This was done in five of the patients of this series. No such contralateral fusion has been necessary, however, in arrests performed since 1947, and this fact further attests to the practical efficacy of the predictions which have been made, and to the value of preoperative serial records. Predictions of the effect of arrests and the timing of the procedures are much more accurate if the patients have been followed serially for some time prior to the surgery, both as to growth and to skeletal age. Occasionally, irregularities of skeletal maturity may exist which make prediction hazardous and, too, the degree of inhibition of growth of the shorter limb may be difficult to evaluate. Under such circumstances, or if there is serious question of overcorrection, one may lean toward stapling.

Stapling has a theoretical advantage in that growth may resume, at least in most instances, after removal of the staples. How dependable this resumption of growth is, we are unable to say. It has been reported by others that staples left in for two years and longer may be removed with reasonable confidence that a normal rate of growth will recur[1, 2, 3]. In our series, since there have been few staplings which have been interrupted during the growing phase, our evidence regarding this is scanty, but it does show that resumption of growth does not occur in all instances. This is well illustrated in the two cases which were described. In some of our patients, the growth after removal of staples was entirely symmetrical in the two extremities and the performance was ideal. If, however, in even one patient such growth does not occur, stapling of an epiphysis cannot be done with the confident assumption that growth will resume after the desired correction has been obtained at whatever age the staples are removed. Procedures based on such an assumption, when the patient is a very young child, may give rise to most disturbing deformities. More information is needed about the incidence of failure to resume growth and about the technique of insertion and removal of staples in relation to this failure of growth. The difficulties that we encountered in some of our patients in removing the staples and the fact that some of the staples, originally extraperiosteal, were found buried in bone indicate the danger of possible injury to the plate and to growth by the procedure of removal itself.

We have used stapling and epiphyseodesis as alternate techniques of arrest, always being guided in the timing of their use by the prediction chart. The fact that growth may resume on removal of the staple gives a margin in calculation which may be important. If future knowledge produces a technique which makes certain the resumption of growth after removal of staples, the need to consider the predicted effect as well as other factors would be of much less importance than it is now. One might then use stapling in various phases of growth.

The possible advantages which may accrue to stapling from the resumption of growth after removal must be weighed against the frequency of complications and secondary operations following the procedure. Although in our experience most of the complications of stapling were relatively insignificant, the procedure, by its nature, does have its uncertainties and difficulties. The frequency of restapling and of secondary procedures for removal of the staples are bothersome to the patient, although the immediate postoperative course following stapling is somewhat less disabling and requires less hospitalization than does epiphyseodesis; also, the individual is able to resume normal function sooner. Actually, with reasonable technical accuracy, complications following stapling and epiphyseodesis should be minimal, provided there is systematic and intelligent observation following the procedure. It was our policy in this series to follow the patient with orthoroentgenograms at three-month intervals during the first year, and thereafter, at six-month intervals until growth was completed. Lateral roentgenograms of the knees were

made at six-month intervals. Evidence of most complications may be seen within eighteen months after surgery and when observed, correction should be promptly done. If, for example, staples are not holding well, they should be re-inserted rather than let deformity arise (Case 3).

We use both epiphyseodesis and stapling and often combine them when a procedure is indicated at two levels. If we need all the correction that can possibly be attained at an epiphyseal level, or at two levels, that is, the upper end of the tibia and the lower end of the femur, we prefer to use epiphyseodesis since this accomplishes our objective promptly and effectively, once and for all. When there is question as to correct estimation of skeletal maturity, however, difficulties in prediction following arrest are exaggerated if epiphyseodeses of the femur and of the tibia are performed at the same time. Such potential errors may be minimized by performing an arrest at one level and observing its effect, and then at a later time performing an arrest at the second level as indicated, in order to get the desired correction. A common practice at the present time, if correction at two levels is needed, is to perform an arrest of the tibia and the fibula by epiphyseodesis at the same time that a stapling of the femur is done. In this event, the latter procedure provides the possibility of removing the staples if necessary to prevent overcorrection. We have never performed stapling at the two levels at the same time. In choosing an epiphysis for stapling, the femoral epiphysis is to be preferred, all other things being equal, since the procedure in the tibia and in the fibula is more difficult and complications are more likely to arise.

Both stapling and epiphyseodesis have their particular values and indications, but further observations are needed before final assessment of their relative merits and uses can be made. In particular, more information is needed about variations in skeletal maturation as they apply to predictions, and further experience must be accumulated as to the performance of growth of the epiphysis after the removal of staples. Until further modifying evidence arises, stapling as well as epiphyseodesis must be considered as a technique of complete arrest. If stapling is performed, it should be realized that complete cessation of growth may occur even if the staples are removed.

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DISCUSSION

Dr. Walter P. Blount, Milwaukee, Wisconsin: Let me emphasize that epiphyseodesis is still a most satisfactory operation if it is impossible to make up the entire difference in limb length by stapling.

I want to speak about the resumption of growth after the removal of staples (slides were shown). This roentgenogram which has appeared in two of our published articles was made four and one-half years after

(*Continued on page 901*)

Aneurysmal Bone Cyst

Observations on Fifty Cases *

BY LOUIS LICHTENSTEIN, M.D., LOS ANGELES, CALIFORNIA

From the Department of Pathology, Wadsworth General Hospital, Veterans Administration Center, Los Angeles

Within the last several years, pathologists, roentgenologists, and surgeons have become increasingly aware of the peculiar bone lesion we called aneurysmal bone cyst [8, 9, 10, 11]. Observations on sizeable groups of cases and the clinical implications have now been published [1–15] both here and abroad. The prevalence of the condition may be judged further by the fact that the writer has seen material from as many as fifty cases since 1948, most of which were submitted for consultation. Some thirty-three of these have not been previously reported [10, 11] and the roentgenograms illustrated in this paper have been selected entirely from this latter series with a view to amplifying recorded experience.

These accrued observations have fully substantiated the concept that aneurysmal bone cyst represents a not uncommon clinical and pathological entity [10], however one chooses to interpret its pathogenesis. The writer adheres to the view that the condition apparently results from some persistent local alteration in hemodynamics leading to increased venous pressure and the subsequent development (in ramifying bayou-like fashion) of a dilated and engorged vascular bed within the transformed bone area. The reasons for favoring this interpretation and, collaterally, for rejecting the various suggestions that the lesion is an atypical giant-cell tumor or an unusual hemangioma or that it conceivably results from subperiosteal or intramedullary hemorrhage alone, have been stated in detail elsewhere [10, 11]; for the sake of brevity, these will not be reiterated here.

At all events, the affected bone site, whatever its location may be, is completely transformed and ultimately comes to resemble an expanded, blood-filled sponge, which may in time attain impressive size (Fig. 15-E). The communicating pools of venous blood within this reservoir are bordered by a brownish fibro-osseous meshwork (Figs. 14-A and 14-B) showing microscopically more or less conspicuous giant-cell reaction to inordinate vascularity and hemorrhage, as well as fields of osteoid and new-bone deposition by way of attempted reconstruction. These peculiar pathological changes (as seen, for the most part, in material obtained by curettement and in occasional intact resected specimens) are being recognized by well informed pathologists with increasing frequency.

The roentgenographic picture reflecting these changes is also sufficiently distinctive, at least in large limb bones and the vertebral column (the commonest sites of localization), to enable one to suspect the condition in the majority of cases, if he is familiar with it. The affected bone area is characteristically more or less expanded, appearing cystically transformed and often eccentrically ballooned-out to a striking degree.

Notwithstanding, it is apparently still exceptional for the condition to be recognized clinically prior to surgical exploration, and it is mainly this circumstance that has motivated the publication of the present paper. As indicated, repetition of considerations previously discussed [10, 11] has been kept to a minimum, consistent with good orientation. Emphasis will be placed mainly upon the recognition of aneurysmal bone cyst through the liberal use of illustrative roentgenograms and upon its appropriate treatment in various situations, particularly in the vertebral column. In particular, the potentially serious hazards of undue delay in treatment and of injudicious therapy, be it surgical or irradiation, will be stressed.

* Part of this material was presented at the meeting of the Northern California Section of the Western Orthopedic Association at Pebble Beach, California, March 3, 1956.

FIG. 1-A

FIG. 1-B

FIG. 2

FIG. 3

Fig. 1-A: Roentgenogram of an aneurysmal bone cyst as it appeared originally in the intertrochanteric region of the femur of a man twenty-three years old. The lesion was curetted and was packed with bone chips. (It was the impression of the local pathologist that the lesion was fibrous dysplasia.)

Fig. 1-B: Re-examination two years later because of pain in the hip region showed recurrence of the lesion, extension beyond its initial limits, and obvious expansion of the affected bone. Review of the original postoperative roentgenograms indicated that curettement had been incomplete. Because of the large size and location of the recurrent lesion, roentgen therapy was administered (approximately 2000 r total dose). At follow-up one year later, the patient's clinical progress was considered satisfactory and roentgenograms showed progressive sclerosis.

Fig. 2: Roentgenogram of another aneurysmal bone cyst in a fifteen-year-old schoolgirl which transformed the medial end of the clavicle into an expanded, tumor-like mass, measuring three inches by four inches in its greatest dimensions. It had increased rapidly in size over a period of observation of four months. Excessive bleeding and proximity to large vessels interfered with surgical extirpation. Subsequent irradiation therapy resulted in sclerosing of the lesion and in halting its progress.

Fig. 3: Another expanded aneurysmal bone cyst in the proximal end of the ulna (one of four comparable lesions encountered in this location). The lesion was thought to be a giant-cell tumor at time of surgery and was treated by curettement and packing with bone chips.

FIG. 4-A

FIG. 4-B

Fig. 4-A: Roentgenogram of an aneurysmal bone cyst in the lower end of the humerus of an adult, illustrating marked eccentric ballooning of the lesion. Its periphery is faintly outlined, in part at least, by a delicate shell of periosteal new bone.

Fig. 4-B: Follow-up roentgenogram showing the result of surgical reconstruction.

As for localization, instances of aneurysmal bone cyst have now been observed in virtually every part of the skeleton, not only in limb bones and the vertebral column, but also in hand and foot bones, the shoulder girdle, the rib cage, the innominate bone, and even in the calvarium. The commonest sites, as noted, are the long bones of the upper and lower extremities and the vertebral column, which together account for fully 60 per cent of the cases in the present series. Specifically, eighteen instances were encountered in long bones, twelve in the lower extremity and six in the upper extremity. The limb bones most frequently affected were the femur and the ulna (the proximal end, particularly), but this may reflect chance distribution inasmuch as it was in the tibia and fibula that most of the lesions in the limb bones were found in the series reported by Dahlin and his associates, for example. As many as thirteen instances (26 per cent) were encountered in one or another part of the vertebral column, in the cervical and lumbar regions

FIG. 5-A

FIG. 5-B

Fig. 5-A: Roentgenogram of an aneurysmal bone cyst involving the body and neural arch of the sixth cervical vertebra in a ten-year-old boy who had complained of pain in the neck, worse at night, for some two months. The initial impression based on the roentgenographic appearance was that of Ewing's sarcoma or, possibly, eosinophilic granuloma.

Fig. 5-B: Progression of the lesion during the next several months resulted in destruction of portions of contiguous vertebrae (fourth, fifth, and seventh cervical vertebrae). This patient then received roentgen therapy. At follow-up about one year later, he was greatly improved. Substantial re-ossification of the involved cervical spine was seen roentgenographically.

FIG. 6-A

FIG. 6-B

Fig. 6-A: An aneurysmal bone cyst involving the body of the fifth cervical vertebra in a seven-year-old girl, resembling that illustrated in Fig. 5-A.

Fig. 6-B: Roentgenogram shows serious progression of the lesion and extension to contiguous cervical vertebrae because irradiation therapy was not begun promptly. In this child quadriplegia developed after chiropractic treatments. Over a year elapsed before recovery of function in the upper extremities; after sixteen months, she was practicing standing twice a day. Roentgen therapy (total dose of 2000 r) eventually controlled extension of the lesion, but irradiation was not begun until six months after the onset of symptoms.

more often than in the thoracic. The remainder were observed in the following sites: clavicle, two; rib, two; scapula, one; innominate bone, five; skull, three; hand bones, three; and foot bones, three.

With reference to incidence as regards age, it seems significant that approximately two-thirds of the patients covered by this survey were children or adolescents, although the condition is encountered in adults as well. As the base of observation has broadened, it has become apparent also that there is probably no significant predilection for either sex.

TREATMENT AND PROGNOSIS

The progressive enlargement of an aneurysmal bone cyst can be halted and reconstruction initiated by thorough curettement and roentgen irradiation in moderate dosage, or both. The necessity for

This lesion in the fifth cervical vertebra of a child, in contrast to the two preceding illustrated cases, was recognized early, subjected to conservative biopsy for confirmation of clinical impression of aneurysmal bone cyst, and irradiated promptly. Follow-up roentgenograms showed satisfactory healing and there was relief of symptoms.

FIG. 7

FIG. 8-A

FIG. 8-B

FIG. 8-C

Fig. 8-A: Roentgenogram of an expanded rarefied lesion of the body of the fourth lumbar vertebra in a young woman which proved on biopsy to be an aneurysmal bone cyst.

Fig. 8-B: Subsequent collapse of the involved body of the fourth lumbar vertebra. The ballooned transverse process provides a clue to the nature of the lesion.

Fig. 8-C: Lateral roentgenogram showing wafer-like compression of the fourth lumbar vertebra. Further progress of the lesion had been arrested by roentgen irradiation. Foot-drop on one side and peroneal palsy on the other had completely cleared; there was surprisingly little residual disability.

FIG. 9-A

Expanded rarefied lesion in the talus of a seventeen-year-old boy, which proved to be an aneurysmal bone cyst. (The initial impression of the local pathologist had been giant-cell tumor.)

FIG. 9-B

Roentgenogram shows marked expansion of the lesion in the ensuing five months and destruction of contiguous mid-tarsal bones, necessitating a major reconstructive procedure after roentgen therapy had halted further progression. Follow-up roentgenograms made fourteen months after surgery showed consolidation of bone grafts and apparent fusion of the tarsal bones.

prompt treatment by whatever means, once the diagnosis has been established, must be strongly emphasized, lest serious damage be done at the affected site (Figs. 5-B, 6-B, 9-B, and 15-E). As previously noted, an untreated or poorly treated aneurysmal bone cyst may eventually attain impressive if not huge size, sometimes necessitating amputation of a limb or, in the case of vertebral involvement, resulting in partial destruction of a number of vertebrae and even irreversible paraplegia.

For lesions in readily accessible sites which are still of relatively small or moderate size, curettement and packing with bone chips is calculated to effect a cure and may well be the treatment of choice. Curettement should be as thorough as the situation will permit. Not infrequently, the surgeon is hampered by persistent welling-up of venous blood from the bed of the lesion and, therefore, stops somewhat short of complete curettement. In these circumstances, a satisfactory clinical result may still be obtained, although one cannot depend upon it. In a recent follow-up survey, the writer encountered four cases in point in which, following incomplete eradication by surgical means, the lesion recurred and subsequently required secondary treatment. It seems advisable, therefore,

FIG. 10

FIG. 11

Fig. 10: An aneurysmal bone cyst transforming the right ischium of a young man of eighteen. The roentgenogram here is less distinctive than those of other cases illustrated.

Fig. 11: An aneurysmal bone cyst thinning and expanding the right mandible of a ten-year-old girl. Treatment was surgical and at follow-up seven months later, the site was said to be practically healed.

FIG. 12

FIG. 13

Fig. 12: A symmetrically expanded, cyst-like rarefaction of the fourth metacarpal bone of a ten-year-old boy (an aneurysmal bone cyst). The surgeon elected to resect the involved bone, although thorough curettement would have sufficed for cure. The expanded cortex was markedly thinned but intact; the interior was filled with "soft, focally hemorrhagic, multicystic fibrous tissue".

Fig. 13: An advanced aneurysmal bone cyst which developed insidiously in an eight-year-old girl and virtually transformed the entire iliac wing. Because of the location and extent of the lesion, roentgen therapy was employed (total dose estimated at 1000 r). At follow-up six months later, there was satisfactory evidence of osseous reconstruction.

FIG. 14-A

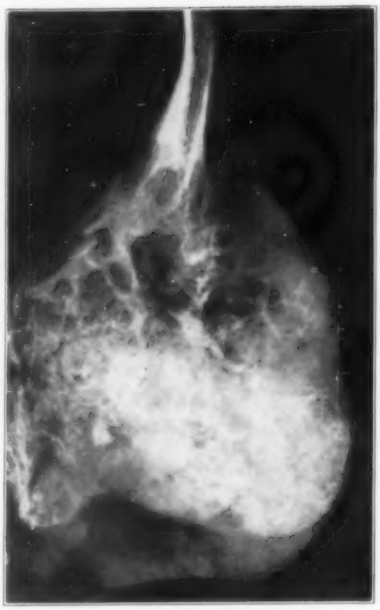

FIG. 14-B

Fig. 14-A: Photograph (two-thirds natural size) of a resected aneurysmal bone cyst of a rib. The patient was a woman thirty-three years old who had been aware of a lump on her rib for about a year. During the last three months of the year, the lump had enlarged quite rapidly and had become painful. Note the honeycombed, sponge-like meshwork within the symmetrically expanded lesion, which was reddish-brown in color. The spaces measured up to 0.5 centimeter in diameter and were filled with blood; the fibro-osseous interstices felt rather gritty.

Fig. 14-B: Roentgenogram of the surgical specimen illustrated in Fig. 14-A.

FIG. 15-A

FIG. 15-B

FIG. 15-C

Fig. 15-A: Initial roentgenogram of a lesion of the foot of a fourteen-year-old girl, who complained of increasing painful swelling of nine months' duration.

Fig. 15-B: Roentgenogram made some five months later. Three unsuccessful attempts at surgical extirpation were made during this interval. Section of one of these specimens is shown in Fig. 15-D.

Fig. 15-C: Subsequent progression of the lesion and development of an egg-shaped soft-tissue mass.

in the event that the surgeon is deterred from complete curettement by disconcerting bleeding or if check of the postoperative roentgenograms demonstrates failure of thorough curettement, to employ supplementary roentgen therapy. This means may also be used to

FIG. 15-D

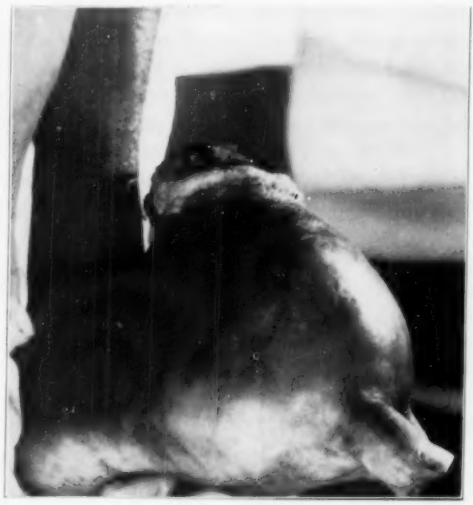

FIG. 15-E

Fig. 15-D: Cross section of the lesion (enlarged) as seen in partially extirpated specimen, showing a honeycombed, sponge-like field, permeated by blood-filled spaces.

Fig. 15-E: Photograph of the patient's foot over a year later, just before below-the-knee amputation was done. (Courtesy of Dr. G. Bras, University College of the West Indies, Jamaica.)

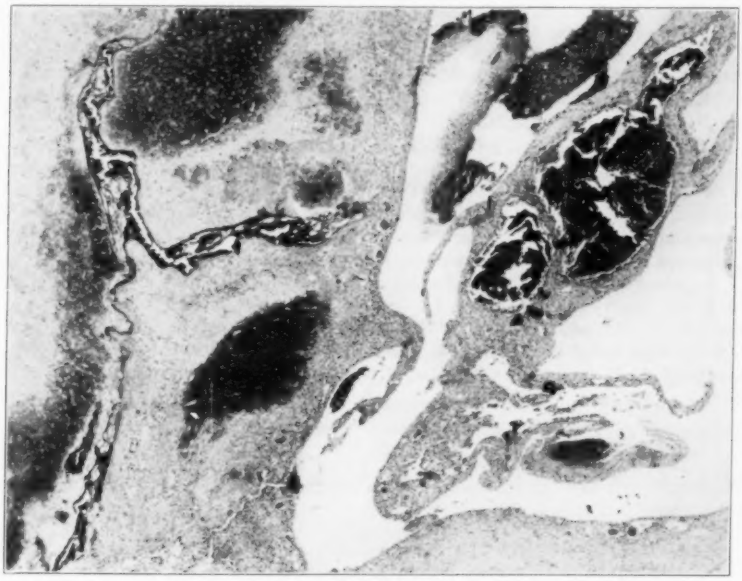

FIG. 16

Photomicrograph of a representative field of an aneurysmal bone cyst showing ramifying pools of blood bordered by fibro-osseous septa, in which one observes blood extravasation and deposition of calcifying new bone. Other fields may show more active osseous reconstruction or prominent giant-cell reaction to hemorrhage.

advantage to control aneurysmal bone cysts which are relatively deep seated or which are encountered in surgically inaccessible sites. The effective dose is not large and previous experience has shown that a total of 1,400 r should suffice for effective control. It is important to emphasize that larger doses than are necessary and exceeding 2,000 r should be avoided because of the potential hazard of the development after irradiation of sarcoma after a latent period of several or many years. The writer [11] has previously called attention to a fatal instance in a child of the development of fibrosarcoma at the site of an aneurysmal bone cyst in the lower portion of the femur which had been intensively irradiated on the mistaken premise that the cyst was a giant-cell tumor.

In dealing with aneurysmal bone cysts which develop in a vertebral body, early diagnosis and appropriate prompt treatment are of the utmost importance. Such lesions, although initially small, may enlarge rapidly and extend to contiguous vertebrae within just a few months, so that the problem of treatment becomes much more formidable (Figs. 5 and 6). If the changes seen by roentgenogram suggest aneurysmal bone cyst, prompt conservative biopsy is indicated to confirm this impression. More extensive surgery with a view to substantially complete extirpation is unnecessarily hazardous and should be avoided. As soon as the diagnosis has been established (by a pathologist familiar with the condition), roentgen irradiation in moderate dosage is indicated before the lesion grows much larger than it already is. As has been emphasized, undue delay or prolonged neglect may have serious consequences.

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Criteria for Determining the Proper Level of Amputation in Occlusive Vascular Disease

A Review of 323 Amputations *†

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In civilian practice, many more limbs are amputated for occlusive vascular disease than for any other cause. The orthopaedist, by reason of his knowledge of the extremity and of rehabilitation of the amputee, should find this problem of interest. Nonetheless the determining of the proper level of amputation is a vexing surgical problem.

Recent articles by Silbert and Haimovici [9] and Shumacker and Moore would tend to favor below-the-knee amputation. Lehman and Figueira, however, questioned the advisability of such amputation, pointing out that use of a prosthesis would hasten the breakdown of the other extremity.

Special methods or tests[6, 10, 11, 12] to aid in determining the level of amputation have not received general acceptance. The importance of a history of recent sudden arterial occlusion in determining the site of amputation has been emphasized by Silbert and Haimovici [9].

Transmetatarsal amputation for certain diabetic lesions of the foot has its advocates [4, 13], but data presented by Warren and co-workers on ten patients with moderate to marked arterial insufficiency revealed that in only two did healing occur when the amputation was through the foot.

Data on the use of a prosthesis by patients with occlusive vascular disease are meager. McKittrick and Pratt, in a follow-up of 138 of 283 patients who had undergone amputations, found that 66 per cent of the 138 used a prosthesis. Silbert and Haimovici [8] reported that in their series 61 per cent of private diabetic patients and 70 per cent of private arteriosclerotic patients used a prosthesis.

MATERIAL AND METHOD

Three hundred and twenty-three major and minor amputations performed at the Mayo Clinic from January 1, 1948, through December 31, 1952, were reviewed. Two hundred and forty-five were major amputations and seventy-eight were minor amputations, the 323 operations being performed on 307 patients. Follow-up data were obtained by letter for all but nine patients. The period covered by the follow-up varied from eighteen months to six years, depending on the time of amputation.

The patients were evaluated preoperatively by means of the history and the physical examination. Special tests were not used; rather, determination of peripheral pulses, venous filling time, color return, and general appearance of the limbs were relied upon. The character of the bleeding at the time of operation was recorded by the surgeon. The vessels of all limbs were examined grossly and microscopically.

The technique of amputation above and below the knee used at the Mayo Clinic has been described by Ivins and Janes.

* Read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28, 1957.

† Abridgment of thesis submitted by Dr. Kelly to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Master of Science in Orthopaedic Surgery.

** The Mayo Foundation, Rochester, Minnesota, is a part of the Graduate School of the University of Minnesota.

REVIEW OF CASES

There were four categories of occlusive vascular disease: (1) atherosclerosis obliterans, (2) atherosclerosis obliterans with diabetes, (3) thromboangiitis obliterans, and (4) a miscellaneous group of embolic occlusions and peripheral aneurysms.

Atherosclerosis obliterans with or without diabetes and the miscellaneous diseases were classified as acute or chronic. In the group of patients with acute disease were those who had had a sudden arterial occlusion from thrombosis or embolism of the main arterial trunk at the popliteal level or higher within three months prior to amputation. In the group of patients with chronic disease were those who had nothing in the history to suggest

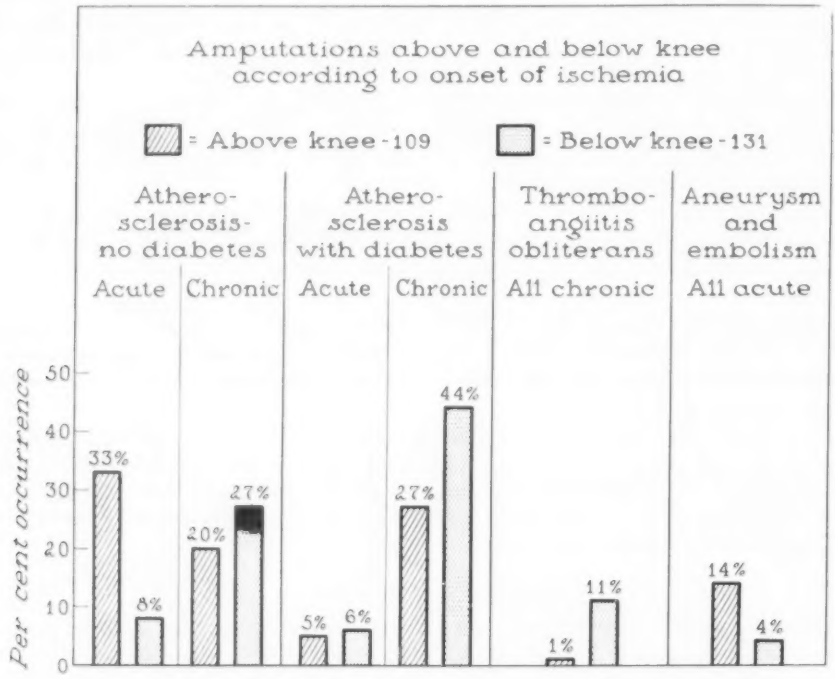

CHART I
Chart excludes five re-amputations

a sudden arterial occlusion within three months prior to operation. For the most part, in the group of patients with chronic disease the lesion was initiated by some form of trauma to an already ischaemic limb. It is well recognized that patients in this group probably had had episodes of thrombosis in the past, but none had had an episode of thrombosis which resulted in a lesion requiring amputation.

In Chart I it is seen that: (1) the atherosclerotic amputees without diabetes had the highest incidence of acute onset; (2) the atherosclerotic amputees with diabetes had the highest incidence of chronic onset and most frequently underwent below-the-knee amputation. Chart II shows that in the majority of below-the-knee amputees there was chronic onset of occlusion prior to amputation. Of the twenty-four below-the-knee amputees with an acute onset, fourteen had serious wound complications. Of the above-the-knee amputations 52 per cent were associated with an acute onset of occlusion prior to operation.

Chart III gives the distribution of cases according to the reason for the above-the-knee amputation. In sixty-nine patients severe ischaemia was the predominant reason. In

twenty-six of this group, there were gangrenous or pregangrenous changes above the mid-portion of the leg, the onset being acute in all but two. In thirteen, poor vascularity was recorded when a test incision was made below the knee; in nine of these the onset was acute. In thirteen, an acute onset associated with a high venous filling time and general ischaemia of the limb was noted. In eight, the femoral pulses were absent; and in nine, peripheral aneurysms were present. The onset was acute in all of these. In the second group (Chart III), consisting of nineteen patients for whom the surgical risk was extremely high, only four were alive one year after operation. The last group (Chart III), consisting of fifteen patients, includes patients in whom re-amputation was performed after below-the-knee amputation had been done elsewhere, patients with severe stasis changes, patients

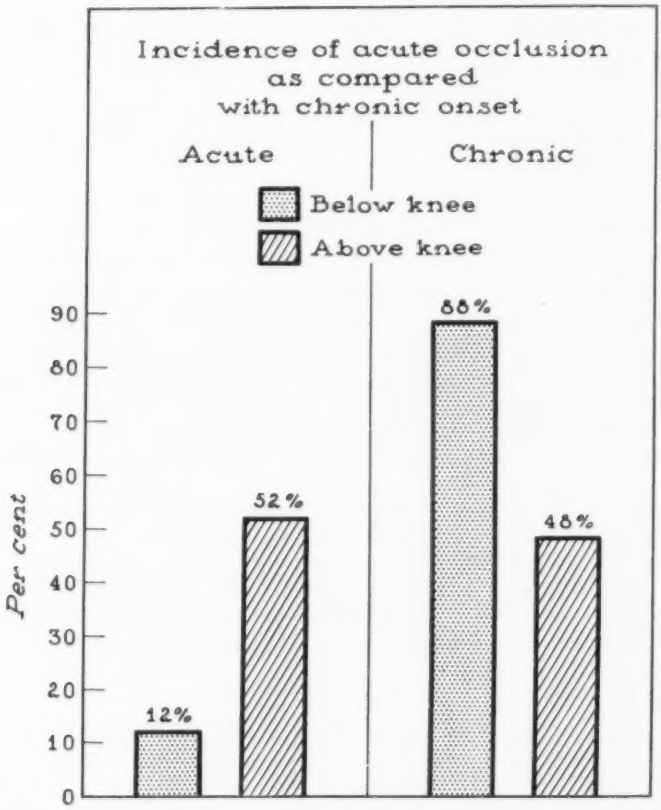

CHART II

with ischaemic ulcers too high for below-the-knee amputation, patients in whom previous amputation, done elsewhere, was followed by postoperative infection, and one patient in whom gas gangrene was possibly present in the limb.

Wound Complications in Below-the-Knee Amputations

Table I summarizes the important factors in thirty-one serious wound complications seen in 131 patients with below-the-knee amputations. In all, forty-one wound complications were listed, ten being minor and healing within a short time following amputation. However, thirty-one were definitely serious: nine required re-amputation above the knee, nine required prolonged periods for healing, and thirteen required surgical revision of the

TABLE I

POSSIBLE CAUSES FOR WOUND COMPLICATIONS AFTER AMPUTATIONS BELOW THE KNEE

		Cases
Re-amputations		9
Sudden arterial occlusion	4	
Trauma to stump	1	
Refrigeration anaesthesia above knee	1	
Aneurysm of femoral artery	1	
Contributing cause undetermined	2	
Major complications of wounds		9
Sudden arterial occlusion	6	
Infection	2	
Contributing cause undetermined	1	
Revisions		13
Trauma to stump after operation	2	
Use of tourniquet at secondary closure	1	
Sudden arterial occlusion	4	
Weak femoral pulse	3	
Distinct line of temperature change above level of amputation	1	
Cause undetermined	2	

stump. The revision usually entailed excision of soft tissue with secondary closure and, at times, removal of one inch of the tibia. Noteworthy is the fact that in fourteen of twenty-four below-the-knee amputations associated with sudden arterial occlusion there were wound complications. At the same time, of the twenty-two patients with major delays in healing or revision of the stump, thirteen were able to use a prosthesis successfully.

Of the 114 eventual amputations through the thigh, only seven were associated with wound complications. In five an acute onset was noted. In addition, femoral pulsations

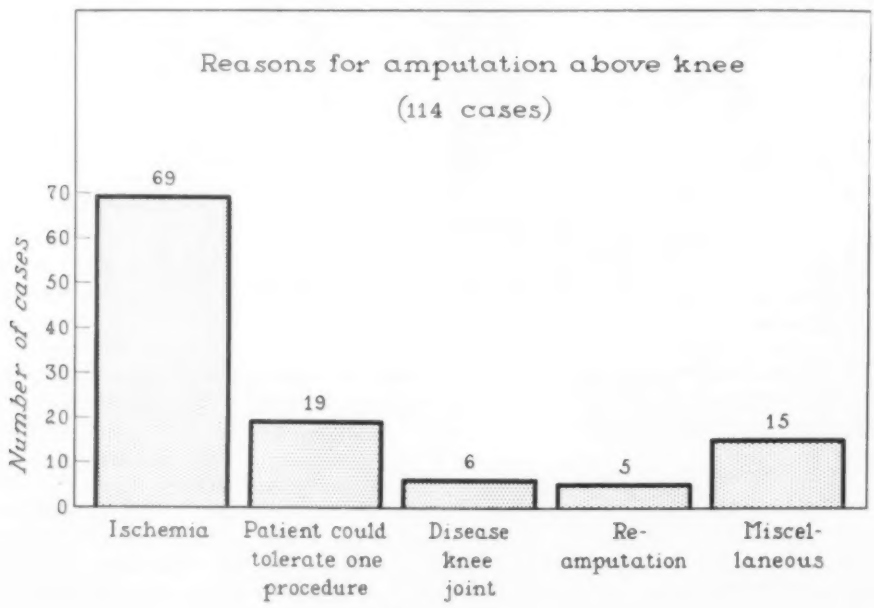

CHART III

TABLE II

RESULTS OF AMPUTATION OF TOES IN SEVENTY-EIGHT CASES

Result	Diabetes	Diabetes and Atherosclerosis	Atherosclerosis	Thromboangiitis Obliterans
Healed	11	15	4	11
Apparently healed; follow-up inadequate	0	3	0	3
Re-amputation (major)	0	14	9	3
Re-amputation needed, but death prevented it	0	3	1	0
Still not healed but no operation as yet	1	0	0	0
Total	12	35	14	17

were absent in five. In three instances, revisions to a higher level were required. Two patients died before the wounds had healed.

Aneurysms and Embolic Occlusive Arterial Disease

There were eleven limbs with a peripheral arterial aneurysm; in ten of these the aneurysm was atherosclerotic and in one the aneurysm was possibly syphilitic. All but one of the limbs eventually required amputation through the thigh. The exception was a limb from which a popliteal aneurysm had been removed before amputation, in an attempt to save the leg. In eight instances of amputation there was embolic occlusion; in four of these amputation above the knee was required, and in two of the remaining four amputation below the knee was a complete failure. It is noteworthy that in all of the patients with peripheral aneurysm or with embolic occlusion, gangrene was ushered in by an episode of sudden arterial occlusion. Embolectomy prior to amputation did not allow amputation at a lower level.

Table II summarizes the data on the toe amputations. It would seem that toe amputation was successful in patients with diabetes in whom the lesions were confined to the toes and were caused primarily by infection or neurotrophic changes. As ischaemia became more evident, success was less certain. At the extreme end of the scale, lesions in patients who had atherosclerosis without diabetes infrequently healed when amputation was confined to the toe. In thromboangiitis obliterans considerable success was noted.

Mortality

There were fifteen postoperative (hospital) deaths in the total series of 323 amputations. Four of the deaths were in the group of 131 below-the-knee amputations and ten were in the group of 114 above-the-knee amputations. These 114 amputations included five re-amputations that had followed failure of re-amputation below the knee. One death occurred in the series of seventy-eight patients who had had toe amputations. The mortality rates were, therefore, 3.1 per cent for amputation below the knee, 8.8 per cent for amputation above the knee, and 1.3 per cent for toe amputation. The combined mortality rate for major amputations was 5.7 per cent.

Open-Flap and Closed-Flap Amputation

The number of amputations below the knee performed by primary closure (sixty amputations) was approximately equal to the number performed by the open-flap method (seventy-one amputations), as described by Jackson and Janes. In our series of cases, healing occurred as readily after open-flap amputation as after closed-flap amputation. The type of closure had no effect on the patient's ability to use a prosthesis.

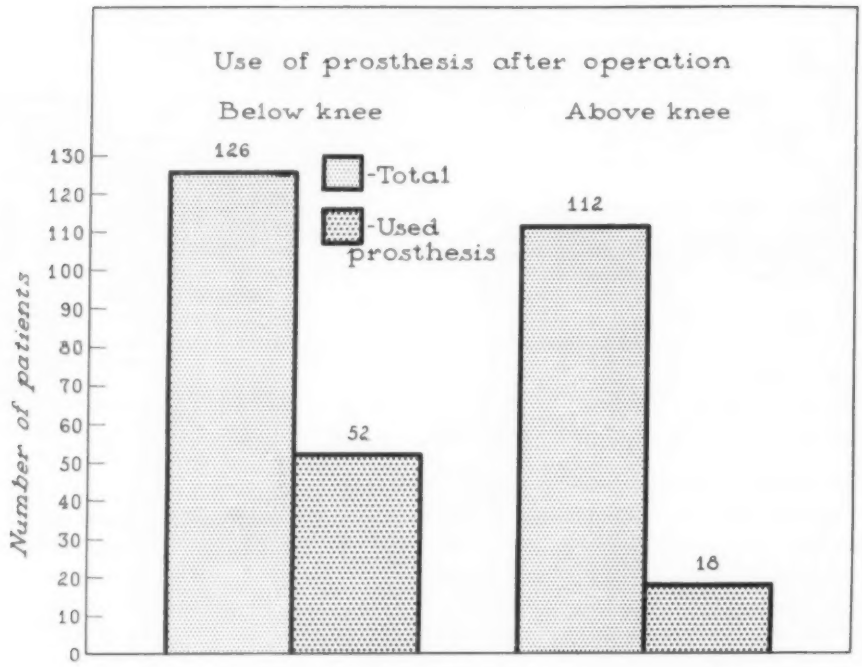

CHART IV

Use of Prosthesis

Adequate follow-up data were obtained in all but nine of the 245 major amputations. The limited data on these nine amputations would make it doubtful that the patients used a prosthesis. Chart IV shows the proportion of patients who used a prosthesis after operation. All except eight of these patients had used a prosthesis for two years or more; the eight patients had used their prosthesis for only one and one-half years.

Lehman and Figueira have said that use of a prosthesis hastens loss of the other leg. This outcome was noted in seven of our fifty-two below-the-knee amputees who used a prosthesis. Three of these patients had thromboangiitis obliterans and each was able to use two prostheses. Four patients with atherosclerosis used a prosthesis for an average of four years before they lost the other limb. Two of the eighteen patients who used a prosthesis after above-the-knee amputation lost the other leg.

The reasons seventy-four patients were not using a prosthesis after below-the-knee amputation are given in Chart V.

COMMENT AND SUMMARY

Some of the broad considerations in determining whether an amputation should be performed below the knee are:

1. A history of slow onset of the disease process rather than a history of sudden arterial occlusion of the main arterial trunk (femoral or popliteal artery) favors amputation below the knee.

2. The presence of a palpable femoral pulse is desirable. Absence of the femoral pulse with a history of recent sudden arterial occlusion contra-indicates amputation below the knee and even may indicate that some difficulty will be experienced with a routine amputation above the knee.

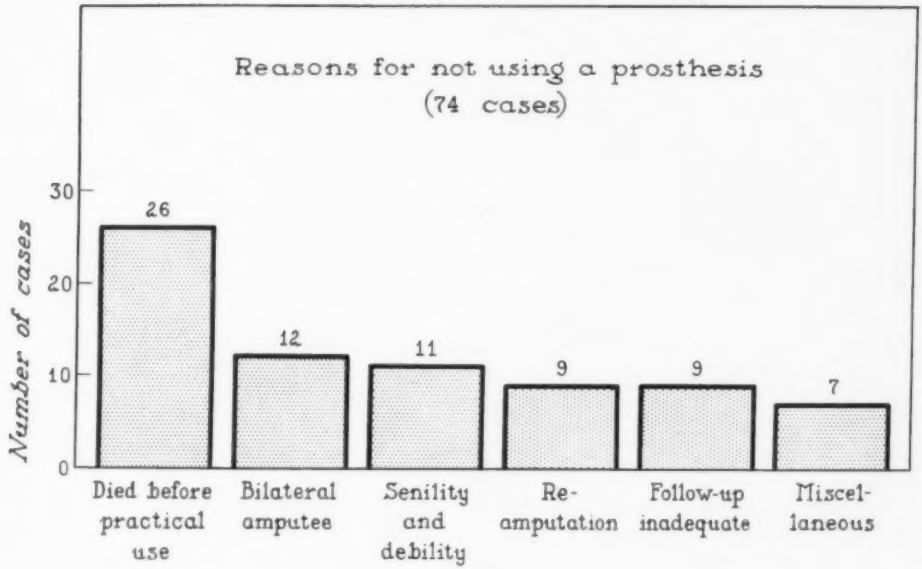

CHART V

3. A functioning knee joint is a prerequisite.

4. The skin to at least the middle of the leg should be unaffected by ischaemic lesions.

5. There should be good bleeding at the site of amputation.

6. There should be some hope of rehabilitation of the patient.

7. Thromboangiitis obliterans may be an indication for amputation below the knee if conservative measures and toe amputation have failed.

The indications for amputation above the knee are:

1. Sudden arterial occlusion combined with a weak or absent femoral pulse;

2. Sudden arterial occlusion if there are other signs such as coolness of the skin above the middle part of the leg, high venous filling time, evidence of severe ischaemia by elevation-dependency tests, or evidence of only fair bleeding at time of amputation;

3. Embolic occlusion and gangrene of the leg caused by a peripheral aneurysm, which usually is atherosclerotic in origin.

The indications for toe amputation are lesions limited to a toe or possibly two toes (1) in patients in whom a clinical diagnosis of thromboangiitis obliterans has been made and in whom conservative measures have been exhausted and (2) in patients in whom purely infectious diabetic lesions have not responded to conservative measures or in patients in whom there are diabetic lesions with minimal occlusive vascular findings. As the signs of occlusive vascular disease increase, the chances of success decrease.

Use of prosthesis: It was disappointing that only fifty-two of the 126 patients with amputation below the knee were able to use a prosthesis. Certainly these fifty-two patients were benefited by being able to use a prosthesis. Fear of losing the other leg should not, in our opinion, be a deterrent to trial of amputation below the knee with the hope of rehabilitating the patient.

Mortality rate: Some have stated that amputation below the knee is indicated because the mortality rate is lower. Superficially, our figures would seem to agree with this; however, in our series, the average patient who underwent amputation above the knee was older and was in poorer general condition than was the average patient who underwent amputation below the knee.

Open-flap amputation: We had hoped that open-flap amputation, as described by Jackson and Janes, would make it possible for more patients to have amputation below the knee. However, the main cause for postoperative difficulty with a below-the-knee stump is ischaemia rather than infection. Adequate use of antibiotics before and after operation aids in the avoidance of infection as a cause of failure in any amputation. This probably accounts for the fact that closed amputation and open-flap amputation worked equally well in our series. However, when infection as well as ischaemia is a problem, the open-flap amputation is an excellent procedure, and there is no reason to believe that the operative wound will not heal as quickly as after closed amputation or that the patient will not be able to use a prosthesis, if he is capable of using one.

CONCLUSION

Experience with amputation in occlusive vascular disease at the Mayo Clinic for a five-year period indicates that the history of onset, the physical findings, and the ulimate prognosis should all be taken into account before one embarks on a conservative amputation. When there is a good chance of rehabilitation of the patient, one may be justified in doing an amputation below the knee in less than ideal circumstances. The fact that thirteen of twenty-two patients who had serious wound complications were able to use prostheses supports this viewpoint; in only two of these twenty-two patients was the stump incapable of supporting a prosthesis because of instability of the stump. Toe amputation can be expected to be successful only in thromboangiitis obliterans and in selected diabetic lesions. Use of a prosthesis does not unduly jeopardize the other leg.

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DISCUSSION

Dr. Robert Mazet, Jr., Los Angeles, California: Dr. Janes and Dr. Kelly have called to our attention two important problems: (1) how do we determine the lowest safe level for amputation in patients with gangrene caused by peripheral vascular disease, and (2) who among these people will be good users of a prosthesis? To these questions there is no categorical answer. The most important single factor in determin-

ing the lowest safe level for amputation is the nutrition of the part at the contemplated level. A good blood supply is necessary for healing after surgery and resistance to the trauma of prosthesis wearing. How are we to determine adequacy of circulation at various levels in the diseased extremity? Dr. Janes and Dr. Kelly have expounded a set of rules, based on their sound thinking and experience. They point out that arteriosclerotic gangrene without diabetes is more liable to be acute in onset; that in the acute cases the collateral circulation has not had an opportunity to compensate; and that most of the people whose histories they studied, who had below-the-knee amputations following gangrene of acute onset, suffered serious complications. Of this group, those in whom the deep circulation of the leg was examined on the operating table exhibited poor tissue vascularity.

Patients in whom there is an acute onset of gangrene are then not the best candidates for below-the-knee amputation. To this, we should add that the presence of a palpable popliteal pulse is desirable for a below-the-knee amputation. The level of coldness and hyperhidrosis helps to indicate the extent of impaired peripheral blood supply.

The small percentage of below-the-knee amputees using a prosthesis in this group is astonishing. Prognostication as to prosthetic use in amputees with peripheral-vascular disease is difficult. Practices relative to prosthetic prescription for these patients differ markedly in various clinics. Some draw an arbitrary age line and do not advise prosthesis for anyone older than this predetermined age. For the above-the-knee amputee, the use of "elephant boots" or "stubbies" has many advocates. Temporary pylons, or legs, of several types are prescribed by the proponents of these devices.

Knowledge of improved devices and the techniques of fitting and alignment developed in the past ten years are gradually being disseminated among prosthetists, amputee trainers, surgeons, and others interested in prosthetic problems. The influence of these groups, working as teams, should significantly increase the number of these amputees who will use a prosthesis successfully.

Three points of interest to persons concerned with amputation problems should be included in the discussion of this paper:

1. Mechanical means for measuring circulation in an extremity, such as the oscillometer, the plethysmograph, the ergometer, skin temperature determinations, and arteriography, have staunch advocates and vehement detractors; each has its virtues and limitations. None can be depended on to evalute the circulation of an extremity or to indicate definitely the lowest safe level at which the surgeon may amputate.
2. Transmetatarsal, tarsal, or Syme amputations are of definite value in selected cases.
3. The use of homogenous arterial grafts, endarterectomy, and lumbar ganglionectomy will sometimes obviate the necessity for amputation. Excision of the lumbar sympathetic chain is of doubtful value in atherosclerosis, but it is often beneficial in thromboangiitis obliterans.

Dr. Ormond Julian, Chicago, Illinois: I would like to point out that when one amputates an extremity, he wants not only a healed stump but also a useful stump. From this point of view, when a below-the-knee amputation heals but the patient cannot walk on the stump because of such symptoms as coldness and tenderness, the amputation is, in one respect, a failure.

I agree on the general failure of tests which have been designed to gauge the adequacy of circulation in determining the level of amputation. The flourescein test, lustamine wheal, and other tests of that kind have found no lasting place in our experience in this important problem. The possible exception to this is the arteriogram.

The level of the pulses, it seems to me, is of primary importance. A toe or metatarsal amputation rarely heals in the absence of a popliteal pulse and usually fails unless the ankle pulses are present. This situation rarely exists except in Buerger's disease or arteriosclerosis with diabetes. Below-the-knee amputation similarly fails in patients having weak or absent femoral pulses.

In addition to the observation as to the presence or absence of pulses in determining whether the femoral circulation is adequate for an above-the-knee amputation, we have learned to pay attention to two other points. One is the x-ray finding of calcification that may be present diffusely through the iliofemoral system, which we believe diminishes the value of a strong femoral pulse. The second is the presence of a bruit over the femoral artery in the femoral triangle. This observation has been made and recorded in all of our patients and when it is present, it indicates proximal disease in the iliac artery and considerably diminishes the positive finding of a femoral pulse. The disease which causes the bruit is likely to become progressively worse and contra-indicates a below-the-knee amputation.

Dr. Janes (closing): In dealing with gangrene that is the result of sudden arterial occlusion, below-the-knee amputation is likely to be unsuccessful. Transmetatarsal amputations were not successful in our experience when the gangrene was due to atherosclerosis obliterans. Ineffective teamwork on the part of the surgeon, the limb-fitter, and the limb-maker is one reason why we failed to have more patients use their prostheses. We now have the services of a limb-fitter and a limb-maker in our locality, and I hope that we shall be able to have an increased number of patients wear their prostheses following both below-the-knee and above-the-knee amputation.

Bone Changes in Chronic Circulatory Insufficiency

A Histopathological Study*

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Avascular necrosis of bone and the process of creeping substitution by which repair is effected are well known sequelae of traumatic interruption of the vascular tree. That this process of necrosis and repair occurs on a smaller scale as part of the normal aging of the skeleton is seldom appreciated.

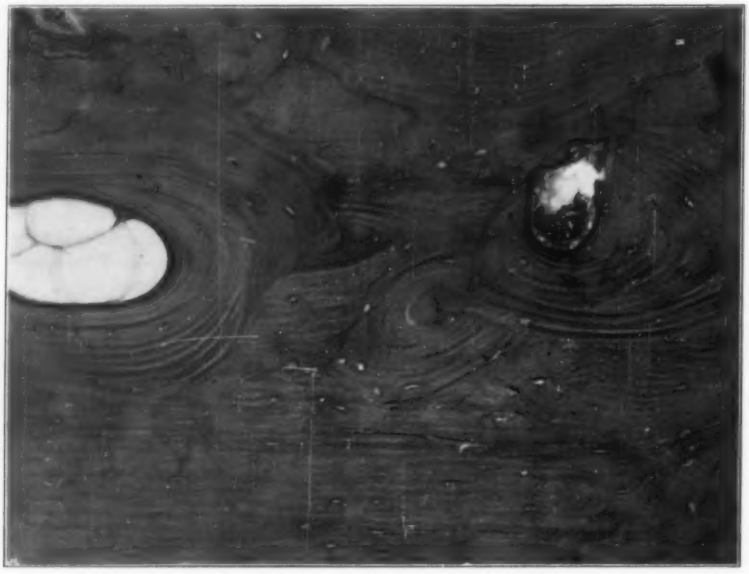

Fig. 1

High-power photomicrograph of bone from the calvarium of a fifty-year-old woman. There are osteocytes clearly visible in the lacunae immediately surrounding the Haversian systems, but elsewhere they are absent.

It is generally accepted that in the continuous remodeling of adult bone, formation of new bone may slowly obliterate part of one Haversian canal, while elsewhere in the same system concomitant resorption of the bone is taking place. The central formation of new lamellae is accompanied by a gradual decrease in the accessibility of the peripheral lamellae[2]. Until the time when bone is physiologically mature, there is slow replacement, by Haversian systems, of the circumferential lamellae laid down in a concentric pattern by appositional bone formation. After skeletal maturity has been reached, the continuous activity of remodeling and reconstruction is just sufficient to meet the functional requirements of the adult bone. In the normal course of events, fragments of necrotic bone result.

Careful study of normal adult bone discloses a variable number of clearly defined areas in which no osteocytes are present[3,5,7]. Changes in the staining qualities of the

* Read at the Annual Meeting of the Orthopaedic Research Society, Chicago, Illinois, January 28, 1956.

calcified matrix are also frequently noted. In these isolated areas of apparent physiological necrosis of bone, there is no evidence of activity to be seen until vascular connective-tissue invasion and creeping substitution begin.

The magnitude of the changes observed depends largely upon chronological age and upon the functional efficiency of the vascular system. It is at adolescence, during the early phase of bone maturity, that physiological necrosis is first seen, but it is usually not prominent until the third decade. Beginning with the formation of a mature type of bone in the young adult, and increasing proportionately with age, this physiological necrosis

FIG. 2

High-power photomicrograph of cortex of the lower portion of the tibia of an active man, forty-six years old. (Amputation had been performed for sarcoma of the upper tibial metaphysis.) The central portion demonstrates a broad streak of acellular bone, although osteocytes are present about the vascular spaces above and below.

is present in all osseous tissue. It is more clearly defined in thick compact cortical bone, as in that of the calvarium and the shaft of the tibia, and it is almost always present in subchondral bone (Figs. 1, 2, and 3).

BONE CHANGES IN CHRONIC CIRCULATORY INSUFFICIENCY

While gangrene seen clinically is visual evidence of interruption of soft-tissue vascularity, neither symptoms nor changes seen roentgenographically can be relied upon to indicate the condition of the long bones with reduced blood supply.

All ten patients of this series underwent amputation of one lower extremity because of inadequate circulation which had resulted in gangrene of various areas of the foot. The ages of the patients ranged from nineteen to seventy years. There were eight men and two women. Arteriosclerosis obliterans was the pathological process in seven men;

FIG. 3

High-power photomicrograph of subchondral area of femoral head removed from a woman, eighty-six years old, a few hours after fracture of the femoral neck. Calcified cartilage is seen at the upper margin. In the central and peripheral portions of the photomicrograph osteocytes are obvious, but elsewhere there are none.

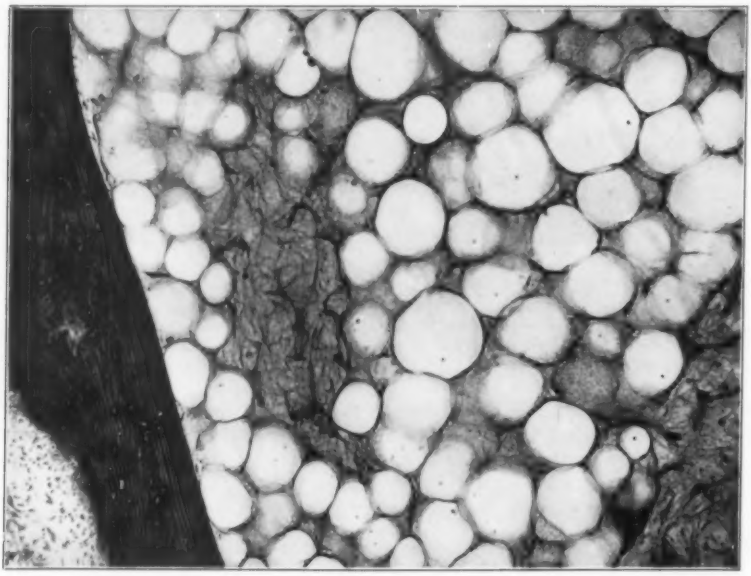

FIG. 4

High-power photomicrograph of tibial bone from the leg of a man, sixty-three years old, who had had symptoms of severe vascular insufficiency for at least four years. No living cells are seen in the marrow spaces, and there are no osteocytes in the inner portion of the bony trabecula. At the border, where vascular connective tissue has penetrated to the outer surface of the trabecula, osteogenic activity is present.

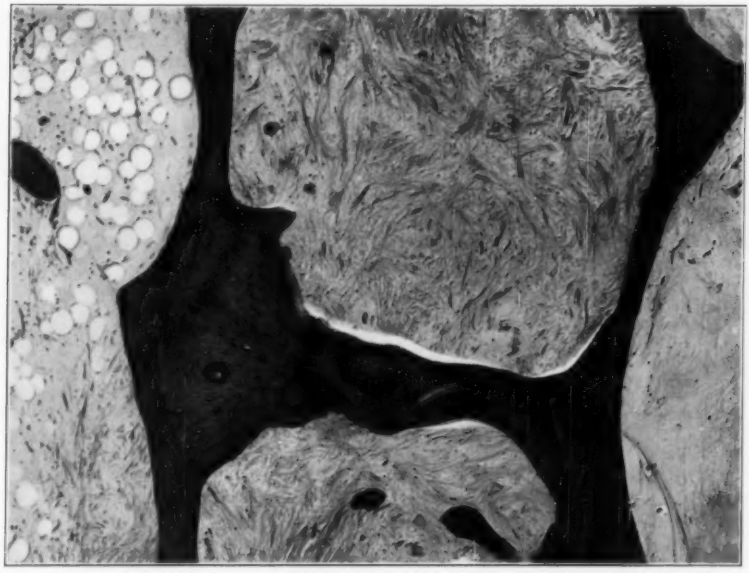

FIG. 5

High-power photomicrograph from cancellous portion of tibia of a man, sixty-eight years old, who had had intermittent claudication for at least two years. There are no osteocytes in the bone. On the right there is acellular necrotic débris; in the center there is inactive dense fibrous tissue; on the left there is oedematous fibrous marrow. This represents the advancing edge of the wave of revascularization. The process of bony substitution has not yet begun.

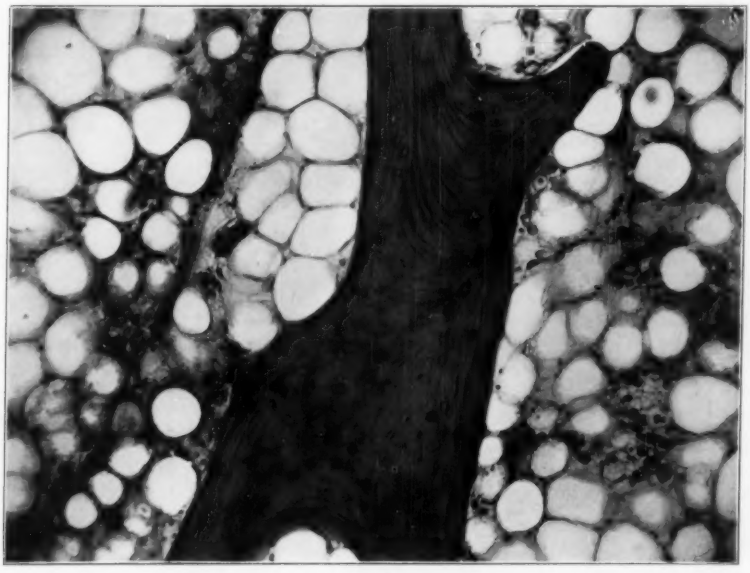

FIG. 6

High-power photomicrograph of bone from the tibia of a man, sixty-one years old, who had had chronic symptoms from Leriche's syndrome for three years. The bone is without osteocytes, and the remains of necrotic fatty marrow can be identified. Vascular connective tissue has penetrated this far, however, and many histiocytes, which are swollen with fat, can be seen removing the débris.

the other had Buerger's disease. One of the women sustained a traumatic laceration of the femoral vessels and the other had the tenth known instance of Buerger's disease in a woman[6]. The distal portion of the tibia, which was well above the level of gangrene in all patients, was studied in detail; and, in most cases, the other bones were examined as well. It is to be noted that in every case in which clinical roentgenograms were made, they were (and still are) interpreted as normal. Microscopic examination of the bones of these patients always reveals some degree of necrosis of the marrow and of the bone trabeculae immediately associated with it (Figs. 4 and 5). This reflects functional impairment in the

FIG. 7-A

Figs. 7-A, 7-B, and 7-C: High-power photomicrographs representative of the degree of necrosis which is often observed.

Fig. 7-A: Same case as Figure 4. Longitudinal section of the tibial cortex. Osteocytes are seen in proximity to the three vascular spaces. Elsewhere the bone is completely acellular.

major source of blood supply, the nutrient artery, which appears to be the most vulnerable aspect of the vascular tree of bone. Since the extent of such necrosis is related to the severity of vascular insufficiency, it is, therefore, variable in degree. As revascularization of the necrotic marrow proceeds, pronounced phagocytic activity is evident, and numerous histiocytes laden with necrotic débris are seen (Fig. 6).

An isolated complete disruption of the nutrient vessels to a bone normally affects only the endosteal and marrow circulation. In extensive vascular disease there is usually impairment of the entire vascular tree. In such conditions, the periosteal as well as the

FIG. 7-B

FIG. 7-C

Fig. 7-B: Cross section of tibial cortex of a man, sixty-eight years old, who had had symptoms of chronic circulatory insufficiency for at least eight years. Only a few osteocytes can be identified about some of the canals.

Fig. 7-C: Same case as Fig. 5. In a longitudinal section of tibial cortex, osteocytes can be seen only in relation to the vascular canals.

nutrient artery circulation of the bone is decreased[4]. Thus, the central necrosis is usually accompanied by marked cortical changes. Evidence of necrosis of an entire Haversian system is common and often most of the cortex appears dead. Figures 7-A, 7-B, and 7-C are representative of the changes commonly found in these cases; they show the variable degree of necrosis which can be present.

When the extra-osseous vascular system is adequate to preserve the periosteum, capillary invasion and marked resorptive changes occur in the necrotic bone. The Haversian canals become greatly enlarged by energetic osteoclastic activity so that the once thick cortical bone takes on a pattern like that of spongy bone. Large vascular

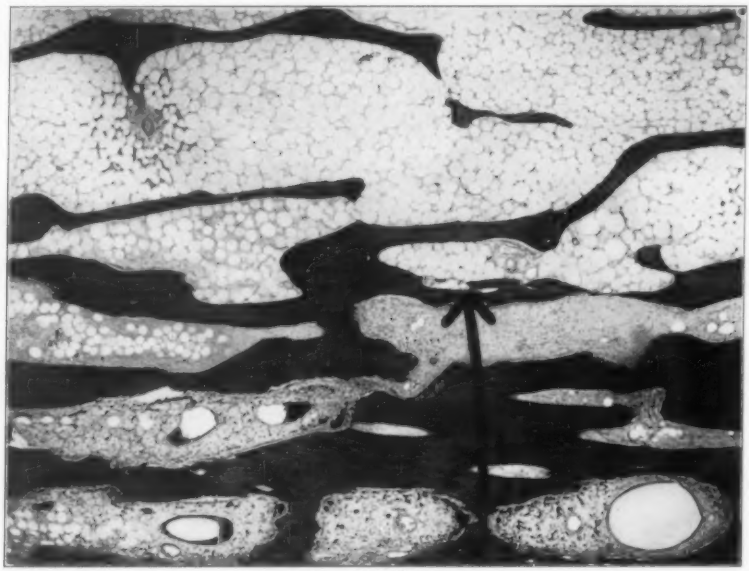

FIG. 8

Same case as Figs. 4 and 7-A. High-power photomicrograph of longitudinal section of tibial cortex in which, as revascularization has proceeded, there has been tremendous resorption of necrotic cortex. The border between the live invading tissue and the still necrotic central marrow is evident.

spaces associated with loose fibrous connective tissue fill the canals, and frequent areas of active osteoblastic activity are seen (Fig. 8).

In addition to the changes noted in the cortical bone, there are also focal areas of revascularization deep in the medullary space, most commonly in the metaphyseal region. Large vascular spaces surrounded by loose fibrous tissue that contains capillary proliferation so marked that it often resembles hemangioma are characteristic where revascularization has been established (Fig. 9-A). Associated with such areas, removal of necrotic débris and energetic osteoclastic and osteoblastic activity is seen. When the compensatory revascularization is interrupted, necrosis of the repaired tissue occurs; all that remains is necrotic loose fibrous tissue with faint outlines of capillaries, phagocytes, and other cells. All newly formed bone also becomes necrotic (Fig. 9-B).

DISCUSSION

The presence of necrotic areas in normal bone and the unusual degree of necrosis seen in the bones of extremities amputated for peripheral vascular disease have been noted by others[2,5]. There is a close correlation between these changes and those found in experimental work which has been performed to demonstrate the blood supply of bone[4].

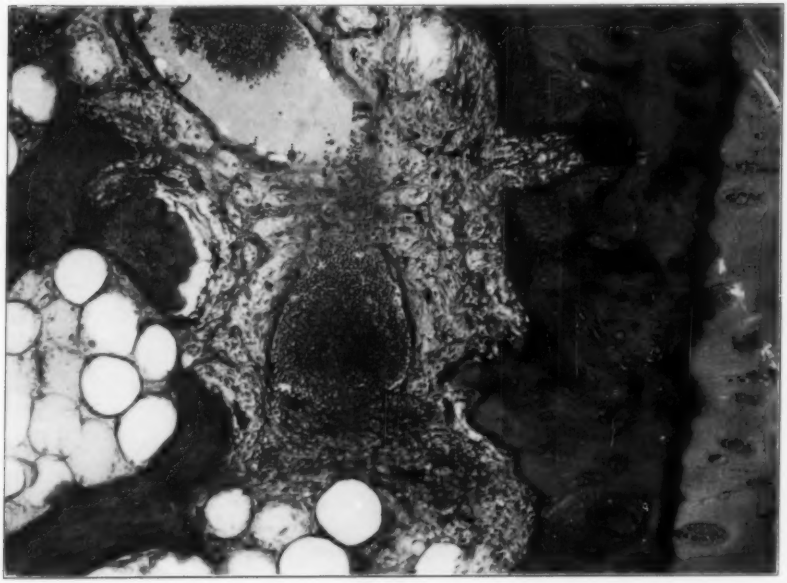

FIG. 9-A

Same case as Figs. 4, 7-A, and 8. High-power photomicrograph of central portion of subchondral plate of distal portion of the tibia in which no cells are visible in any of the bony lacunae. At the left of the figure there is necrotic fatty marrow. Elsewhere in the marrow spaces there is vigorous revascularization. Note the enormous vascular spaces surrounded by loose connective tissue in which there is pronounced capillary proliferation.

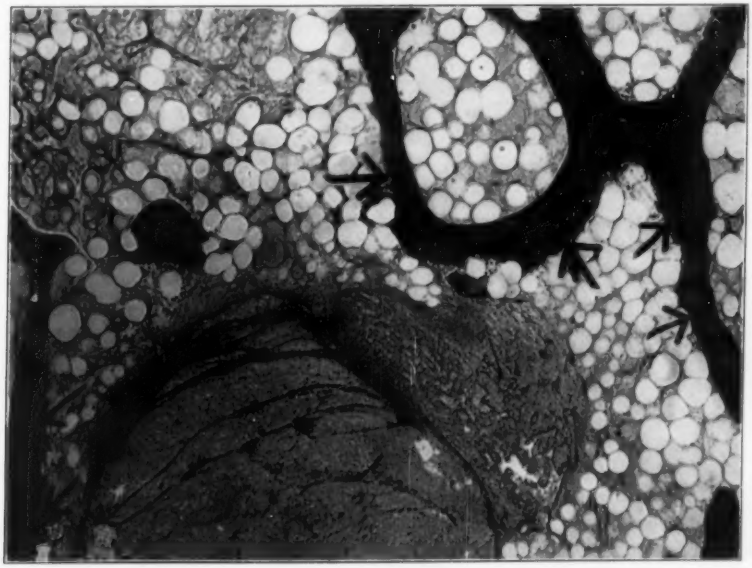

FIG. 9-B

A little deeper in the metaphysis of the same tibia is evidence of successive episodes of acute ischaemia. A large blood space surrounded by capillary proliferation had induced delicate new-bone formation on the surface of nearby regional trabeculae. Now, however, the repair process has been deprived of sufficient vascular supply and the entire area is necrotic.

FIG. 10

High-power photomicrograph of external surface of tibia of a nineteen-year-old girl who underwent amputation forty-eight days after acute laceration of femoral vessels in Hunter's canal. Note, in addition to the invasion of the cortex, the marked periosteal new-bone formation.

Since the morphological changes which result from chronic impairment of blood supply to bone are so profound, it is surprising that there are so few clinical indications of them. Occasionally, when vascular invasion of the cortex and periosteal new-bone formation have become extensive, there is a slightly mottled shaggy appearance on the roentgenogram[3] (Fig. 10). It may be this periosteal activity which is responsible for the aching bones of which some patients complain.

The slow process of revascularization and replacement explains the preservation of functional strength which is so striking[1]. In one patient in this series the tibia was found to be completely dead except for a few Haversian systems, but the only symptoms present were those of vascular disease. The weight-bearing functions of the tibia were in no way impaired. This same explanation accounts for the fact that healed segmental fractures of long bones, even when the roentgenographic appearance of the central fragment indicates necrosis, do not collapse. This is in obvious contrast to what occurs when necrotic cancellous bone, which is invaded much more rapidly, is exposed to weight-bearing stress. This preservation of strength bespeaks the efficacy of cortical-bone grafts whenever structural support is needed in addition to osteogenic stimulation.

CONCLUSIONS

1. In normal adult bone there is a variable amount of focal necrosis which occurs as part of the normal aging of the skeleton.

2. The extent of this necrosis increases with age and is related to the physiological aging of the vascular system and not to abnormalities of the osseous system.

3. Chronic peripheral vascular disease greatly increases the amount of necrosis of bone.

4. In the presence of severe chronic vascular insufficiency, there may be such massive necrosis as to include most of a long bone, such as the tibia, without any resulting changes in the clinical or roentgenographic picture.

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DISCUSSION

Epiphyseal Arrest

(*Continued from page 872*)

staples were inserted and after the complete correction of deformity. The tibia was previously too long, and there was knock-knee as the result of osteomyelitis. The next roentgenogram was made three months after removal of the staples. Markers were inserted in the epiphysis before closing the wounds. A similar marker was also inserted in the normal *left* epiphysis.

The last roentgenogram, made ten months later, following removal of the staples, shows conclusively that the affected right tibia grew fourteen millimeters at the proximal end while the normal side grew nine millimeters at the proximal end. This temporary acceleration of growth on removal of the staples is the rule. After this roentgenogram was made, growth progressed symmetrically.

The rate of growth in another patient is better seen in three consecutive roentgenograms on the same slide. On the left is the appearance of a distal femoral epiphysis one month after removal of the staples. The staples of the tibia were left *in situ*. Note the bulbous appearance of the distal end of the femur, resembling a Florence flask. This is characteristic of a stapled femur and is due to tubulation without longitudinal growth. In the center roentgenogram, made ten months after the removal of the staples, the shape is more normal, rather that of an Ehrlenmeier flask. Note that the growth is practically symmetrical. There is actually a gain of two millimeters on the stapled side, a temporary slight acceleration. You will note from the third roentgenogram, made two years later, that growth has proceeded symmetrically. Note the height of the tiny markers in the epiphyses. In the roentgenogram on the left they are symmetrical. They remain so in the middle roentgenogram at a higher level. In the third roentgenogram they are near the top of the slide and are still symmetrical. Since then, growth has proceeded equally on the two sides. Other such cases have terminated similarly, but it is rare that one has an opportunity to study a case long after the staples are removed. Other evidence which is more frequently available is the continuation of symmetrical growth after the staples for the correction of a knock-knee deformity have been removed. Such results have been published many times and should be convincing evidence that growth usually does proceed normally after the removal of staples.

Hematogenous Infection of Closed Fractures with *Mycobacterium tuberculosis**

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Tuberculous infections of bones and joints occur as a result of metastatic spread of the *Mycobacterium tuberculosis* through the blood stream. A primary complex of involvement of the chest or lymphatic glands must exist before the bone or joint lesion can develop, whether it can be demonstrated or not. It is self-evident that tuberculous bacteriemia must seed thousands of locations within the body at any one time, yet only a few develop into the florid picture of the actual destructive lesion. It would not be surprising if multiple bone or joint lesions were the rule, yet solitary lesions are the usual form. No adequate explanation of this phenomenon has ever been proposed. Trauma, as a localizing factor, has never been satisfactorily established in most instances. That severe trauma to a joint has, on occasion, been followed after an interval, by the development

FIG. 1-A

FIG. 1-B

Fig. 1-A: Case 1. J. B. Roentgenogram made one and a half years before the fracture of the left femur.
Fig. 1-B: Four months before fracture.

of a tuberculous infection in that joint has been occasionally demonstrated; that the trauma and subsequent tuberculosis were indeed allied can still be only a creditable assumption. In most instances, the development of the tuberculous bone or joint lesions is entirely without recorded trauma.

In most instances, therefore, tubercular bone or joint lesions appear to be seeded without relation to trauma, and the lesions are probably located close to the filtering apparatus of the small arterioles at joint structures or at bone metaphyses. Since many foci must be seeded in any one period of tubercular bacteriemia, since few foci develop into the active stage, and since the body as a whole at the time of seeding must be in the particular balance necessary for the implantation of the infection, it is logical to suppose

* Read at the Orthopaedic Section of the New York Academy of Medicine, April 16, 1956.

that some specific factor, unknown at present, must exist which finally permits the localization and the development of the lesion.

In the past, an occasional patient has been encountered at Sea View Hospital with a simple fracture never operated upon, in whom, within a period of time consistent with the age of the patient, tuberculosis in the fracture site developed. These patients have been rare and are worthy of mention only as they are subjects for discussion. They exist in the hospital records and in the memory, and they are extremely difficult to trace for follow-up observation.

FIG. 1-C

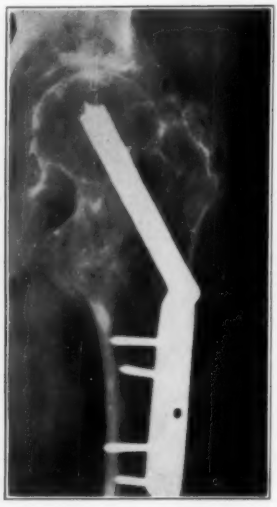

FIG. 1-D

Fig. 1-C: Roentgenogram made at the time of the fracture, April 1949.

Fig. 1-D: Nine months after the injury, February 1950.

At present, at Sea View Hospital there are three patients demonstrating this problem. All three had fractures through undiseased areas of the proximal portion of the femur. In two, reduction and internal fixation of the fracture was done and healing occurred; in one, no surgery was done. Months later the area was found to be tuberculous.

CASE 1. J. B., a man, sixty-eight years old, was admitted to Sea View Hospital in December 1947. In April 1949, he fell to the floor and sustained a comminuted intertrochanteric fracture of the left femur.

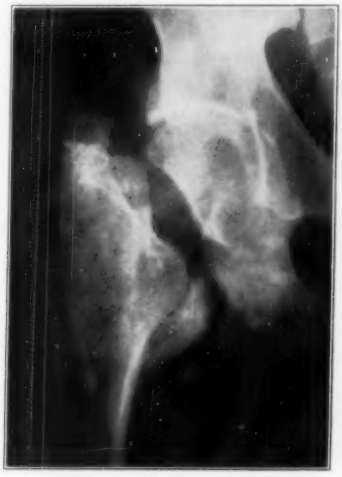

FIG. 2-A

FIG. 2-B

Fig. 2-A: Case 2. G. B. Roentgenogram of ununited fractured neck of the left femur two years after injury. Tubercular involvement of the hip joint was discovered at that time during an operation for a prosthesis implantation.

Fig. 2-B: Roentgenogram made six months after operation showing that the lesion has become quiescent and healing has taken place.

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 3. V. S. Roentgenogram made August 1955, at the time of fracture.

Fig. 3-B: Seven months after injury, March 1956.

Reduction and Jewett nail fixation was done within two days. He progressed normally but continued to use crutches partly because of the need of support due to severe involvement of the chest and general body weakness and partly because of the residual effects of the fracture. Six months later, pain and stiffness of the left hip developed and continued thereafter. He died in June 1952, of advanced pulmonary tuberculosis. At autopsy, the fractured hip-joint area was exposed and wide-spread tuberculous involvement of the area was found.

This patient was under treatment for pulmonary tuberculosis at Sea View for two years prior to fracture. During this period he had never complained of symptoms referable to the left hip, and roentgenograms made of his hips in the routine hospital skeletal survey in 1948 and in 1949, before the accident, did not reveal tuberculous foci there. This man had far advanced pulmonary tuberculosis with metastatic tuberculous lesions in the epididymis and tuberculous involvement of the retroperitoneal lymph nodes.

CASE 2. G. B., an elderly, alcoholic, syphilitic woman living alone, tripped in her home in 1952 and fell downstairs fracturing the neck of the femur. It was not until six months thereafter that the lesion was diagnosed and she was hospitalized elsewhere. At that time, there were active pulmonary tuberculosis and non-union of the fractured neck of the femur. Her injury occurred in December 1952, but it was not until 1954 that she was considered in suitable condition for the implantation of a hip-joint prosthesis. When the hip joint was exposed, tuberculous involvement was seen. The head of the femur was removed. As a tuberculosis patient she was transferred to Sea View Hospital. At the present time the chest lesion has been controlled and the hip lesion has healed by fibrous union. The patient has repeatedly stated that she never had symptoms at her hip prior to the fracture.

CASE 3. V. S., a man, after numerous hospital admissions for alcoholism and for pulmonary tuberculosis which followed a traumatic amputation of the right leg in 1924, fell, in August 1955, and sustained an intertrochanteric fracture of the right femur. Ten days later, reduction and internal fixation of the fracture was done. Because of the presence of pulmonary tuberculosis, he was admitted to Sea View. He was ambulatory on crutches. In January 1956, he began to complain of pain and stiffness of the right hip. Because of the pain, the internal fixation was removed in March 1956, and a large tubercular abscess was found. Anti-tuberculosis therapy was administered. The skin incision has healed, and the process has subsided. The patient stated that he had never had symptoms at the right hip prior to his fall and the fracture.

DISCUSSION

It seems possible that in the presence of tuberculous bacteriemia a severe traumatic lesion, such as a fracture, could lower the resistance of tissue and provide means for the implantation and growth of the tuberculous organisms. It seems to be clear that injury is the predisposing cause of the localization of the tuberculous lesion. This assumption is not intended to imply that all instances of bone and joint tuberculosis are localized by antecedent injury. The conditions for such localization are specific.

Retrosternal Dislocation of the Clavicle

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Retrosternal dislocation of the clavicle is an uncommon lesion. The following presentation was written to emphasize certain special aspects of this condition and to describe the complications and pitfalls which are inherent in its diagnosis and treatment. Six cases are presented as illustrations; in four of these cases follow-up was maintained for six to eight years.

Sir Astley Cooper described the condition in his *A Treatise on Dislocations and on Fractures of the Joints* in 1823. In 1923, Beckman described a case in which simultaneous dislocation of both ends of the clavicle had occurred, the sternal end being dislocated posteriorly. Prat, in 1936, described a similar case; and in 1944, Greenlee presented an excellent historical review with an extensive bibliography. He stated that suprasternal displacement is a varient of retrosternal dislocation, the clavicle in the former lying under the sternocleiodomastoid, and he presented a case in which open reduction had been necessary following failure of closed manipulation. Of interest is the excellent lateral roentgenogram which he obtained, clearly showing the posterior displacement.

Kennedy and Gunther, in 1949, each described one case. Kennedy stated that he had known of two deaths caused by this condition, one due to tracheal laceration and one due to injury to the great vessels in the superior mediastinum resulting in hemothorax. He considered open reduction a necessity. Gunther, in his article, described a case in which successful closed manipulation had been done and stated that only thirty cases had been reported in the literature up to that time.

As recently as 1952, Butterworth and Kirk reported a case of fracture-dislocation of the sternal end of the clavicle.

The sternoclavicular joint is the only articulation between the shoulder girdle and the trunk. Movements at this joint allow the clavicle to ascend, descend, rotate, and move forward or backward. Anatomically the joint is not inherently stable, for the surface of the enlarged sternal end of the clavicle is opposed by the surfaces of the sloping oblique articular facets at the upper angle of the manubrium and adjacent portion of the first costal cartilage. In this joint it is the ligaments rather than the bone surfaces which provide stability.

The joint contains an articular disc, two articular cavities, and two synovial layers between which there occasionally is a communication. The joint is completely surrounded by a capsule which is made up of the strong, firm posterior sternoclavicular ligament and the more lax, less tough anterior sternoclavicular ligament. A strong concave band, the interclavicular ligament, extends across the upper end of the sternum between the two clavicular heads; this ligament is intimately associated with and reinforces the sternoclavicular ligaments. The costoclavicular ligament is broad (1.5 to 2.0 centimeters) and short and connects the clavicle and the capsule of the joint to the first rib. Anterior to the joint is the flat tendon of the sternocleidomastoid, which is of little importance from the standpoint of injury. Posterior to the joint are the trachea, the esophagus, the great vessels, and the vagus nerve, which is partly protected by the soft muscle bellies of the sternohyoid and sternothyroid. These important structures, all of which lie within the superior mediastinum, are often severely damaged in retrodislocation of the clavicle, a consideration which constitutes a strong argument in favor of immediate and complete reduction.

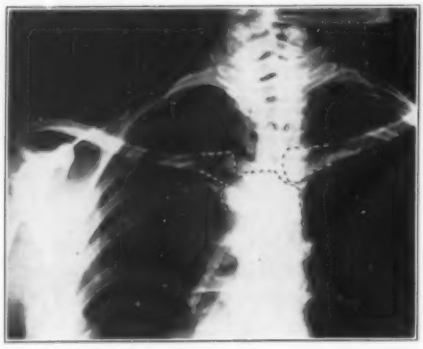

FIG. 1-A

FIG. 1-B

FIG. 2-A

FIG. 2-B

FIG. 3-A

FIG. 3-B

Presumably, the lesion may occur in individuals of any age and of either sex. In the bulk of the reported cases the injuries have been due to trauma—athletic mishaps being the most common cause, and automobile accidents and other types of injuries accounting for many others. In our series all the injuries were of traumatic origin, resulting from either athletic or automobile accidents and all the patients were males between the ages of eleven and twenty-two years. Three of the dislocations were due to automobile accidents, two to football injuries, and one to baseball injury.

There is probably no racial predisposition. One of our patients was a Negro and five were whites. Greenlee mentioned the possibility that the condition might be a congenital lesion.

No pathological studies were made in our series since no open operations were performed. According to Kennedy's report, both the sternoclavicular and costoclavicular ligaments are completely torn.

Because of the presence in our cases of normal stability of the joint following closed reduction, we surmise that the ligaments were only partially avulsed from the clavicle or sternum instead of completely torn and that they subsequently healed in normal position, presumably with normal strength. In one patient the injured clavicle remained slightly more prominent than the opposite one but objectively and subjectively appeared to be stable.

In previous reports the mechanism of injury has been described as either a direct force exerted inward and downward against the sternal end of the clavicle or an indirect force exerted forward and downward on the posterolateral aspect of the shoulder, the shoulder itself being in a forward position. In our series the cause was apparently an indirect force, which is probably the more common type.

The symptoms depend on the degree of displacement. All patients complain of a deep, boring, stifling pain in the region of the joint. This pain is aggravated by any motion of the shoulder girdle including that caused by coughing, sneezing, and deep breathing, but is partially relieved by holding the shoulder and head forward. A feeling of suffocation is present when the displacement is sufficient to cause pressure on the trachea, and there may be a history of unaccustomed snoring following the injury. Dysphagia is also occasionally present. The characteristic protective position is maintained by the patient whether he is standing, sitting, or lying down; and motions of the shoulder and shoulder girdle are limited because of pain. If the lesion is seen early, a depression is found in place of the normal prominence of the sternal end of the clavicle. If examination is delayed, however, swelling and induration may mask completely the pathognomonic signs otherwise found on palpation. Varying degrees of swelling and discoloration may be present, depending on how much time has elapsed since the injury. In patients seen early, as were all the patients in our series, the absence of the normal clavicular prominence may be easily determined by palpation. One must be careful to look for signs of complications such as subcutaneous emphysema, hemothorax, and excessive dyspnoea. The lungs should be examined by percussion and auscultation and possibly also by roentgenography in order to rule out the possibility of damage to the deep structures. Roentgenographic study is important if a sufficiently good view of the joint can be obtained. In heavy or thick-chested individuals, however, this is not always possible. In our experience, the best view is an oblique postero-anterior roentgenogram made with the unaffected shoulder next to the film, a standing Bucky diaphragm being used. In this view the affected joint will not be covered by the shadow of the spine and mediastinum. A roentgenogram of the opposite joint should be made for comparison, the same technique being used. Stereoroentgenography may be helpful and the use of laminagraphy has been advised by Kennedy. We have had no experience with the latter. Figure 1-A is a postero-anterior roentgenogram of the chest showing the normal position of the sternal end of the right clavicle, and Figure 1-B is an oblique roentgenogram of a normal right sternoclavicular joint. In Figures 2-A,

2-B, 3-A, and 3-B, the same views are presented to illustrate the pathological conditions resulting from retrosternal dislocation of the clavicle. These roentgenograms show that separation has occurred.

Roentgenograms by themselves are not diagnostic. Our finding has been that roentgenographic examination of the sternoclavicular joint following anterior dislocation reveals upward as well as medial displacement. In our series, the most characteristic finding of the roentgenograms was that the sternal end of the clavicle was depressed or displaced inferiorly; this was found in all our cases. We consider this finding to be of importance but do not consider it diagnostic. Although such roentgenographic findings cannot be considered diagnostic, their presence should at least alert the examiner to the possibility of posterior or retrosternal dislocation. In each of our six cases, retrosternal dislocation was found clinically. As previously stated, all the patients were seen within one to four hours after injury and all the injuries were reduced almost immediately.

Since the clinical symptoms may be obscured by swelling about the area of the lesion and since roentgenograms are frequently unsatisfactory, it is important to keep retrosternal dislocation of the clavicle in mind whenever any injury at the sternoclavicular joint is present. In some cases the diagnosis can be made definitely only upon reduction of the dislocation. The characteristic discomfort prior to manipulation and the relief following it, when the patient recovers from anaesthesia, constitute dramatic and fairly conclusive diagnostic evidence. Conditions which must be differentiated from restrosternal dislocation are anterior dislocation; fracture of the sternum, clavicle, or first rib; arthritis of the sternoclavicular joint; and strains or subluxations of the sternoclavicular joint. The type of pain is important, and attention should be paid to the pressure symptoms, for those seen in retrosternal dislocation are characteristic. Suspicion is the most important single faculty necessary for diagnosis.

There were no complications in our series. Complications mentioned by other authors have included tracheal laceration; rupture of the subclavian vein or the internal mammary vein or artery or of other great vessels in the area; injury to the pleura, brachial plexus, or esophagus.

Death occurred as a result of some of these complications, and permanent brachial palsy occurred in one reported case.

In general previous authors have felt that some type of open reduction and internal fixation is almost always necessary. Some have resected part or all of the clavicle; some have used wire or pin fixation; and some have fused the joint. In two previously reported cases closed reduction was used with apparent success; in one of these cases, however, there was recurrence of the dislocation two weeks later. In our six cases, closed reduction was accomplished fairly easily (with the patient under anaestheisa), and there was no difficulty in maintaining the reduction.

Our method of obtaining reduction was as follows. The patient was placed on his back, either with a sandbag between the shoulders or with the affected shoulder over the edge of the table. While an assistant applied traction to the arm with the shoulder abducted and extended, the operator grasped the proximal half of the clavicle and maneuvered it upward and forward. Reduction was accompanied by the dramatic "give and snap" which is characteristic of the reduction of most dislocations elsewhere in the body. If a sufficiently firm grasp cannot be obtained on the proximal end of the clavicle, which did not occur in any of our cases, a towel clip inserted through the skin to the proximal end of the bone, as described by Gunther, will probably provide a better hold and will facilitate maneuvering the proximal end of the bone. To obtain immobilization we used a Velpeau bandage or a grenadier (modified figure-of-eight) jacket. Following removal of this dressing after three or four weeks, it was found that no further care was necessary other than to supervise active shoulder exercises until a full range of motion and strength had returned to the extremity.

CASE HISTORIES

The first patient was a nineteen-year-old white male, seen and treated in March 1948. Follow-up examination two years later revealed slight increased prominence of the sternal end of the left clavicle. There was no subjective or objective evidence of any other abnormality, however, and none was reported up to February 1956.

The second case was that of an eleven-year-old white male, seen and treated in May 1949. Examination ten months later revealed a completely normal sternoclavicular joint. Communication with the patient in February 1956 revealed no complaint or abnormality.

In the third case the patient, a sixteen-year-old white male, was seen and treated in August 1949 for retrosternal dislocation of the right clavicle. Examination six weeks later revealed no abnormality of any kind. Communication with the patient in February 1956 revealed that in the interim he had suffered an injury to the right shoulder while playing football but that there had been no recurrence of the dislocation and no consequent disability.

The fourth patient was a sixteen-year-old white male, seen and treated August 20, 1949. Two months after treatment no abnormality was present, and communication with the patient at the end of one year revealed no subjective complaint and no restriction in activities.

In the fifth case a seventeen-year-old colored male was seen and treated for retrosternal dislocation of the right shoulder on October 21, 1949. Follow-up examination six months later revealed no objective evidence of abnormality, although the patient stated that the right shoulder felt stiff on cold days. He was participating fully in competitive sports with no apparent distress. No further follow-up examination was possible.

The sixth and last case was that of a white male, twenty-two years old, who was seen and treated for retrosternal dislocation of the right clavicle on August 12, 1950. Six weeks later the only finding was slight prominence of the sternal end of the clavicle. Six years later, in a personal communication, the patient said that there was no noticeable prominence and that, to his knowledge, he had no disability of any kind.

In none of our six cases has there been, to our knowledge, any recurrence of the dislocation. Furthermore, there has been no restriction of motion of the shoulder and no complaint of restriction of activities.

If treatment is instituted within twenty-four to forty-eight hours of injury and if reduction can be obtained by closed methods and maintained, the prognosis would seem very good. We base this assumption on the results obtained in our series in which slight transient pain or stiffness in the joint caused by exposure to cold were the only disabilities. In this series there was no demonstrable weakness or instability and no limitation of activity. There was also no evidence of traumatic arthritis. In most of the previously reported cases there was delay, usually several days or more, in diagnosis and treatment. We believe that delay is what necessitates open reduction and causes recurrence following closed reduction. It is also possible that in these previously reported cases the injuries were more severe than those in ours, with possible complete avulsion or tearing of the ligaments, so that even if closed reduction could have been accomplished, there might have been instability as a residual complication, creating the same problems as are found in anterior dislocation.

SUMMARY

Retrosternal dislocation of the clavicle is an uncommon lesion which in unskilled hands may be difficult to diagnosis, with the result that treatment is often delayed. In most of the previously reported cases, delay has necessitated the use of open operation and internal fixation. In the series of six cases presented here, early diagnosis and treatment made the use of closed reduction possible and resulted in an uncomplicated postreduction course with no significant permanent disability. Since roentgenographic findings are sometimes inconclusive, the importance of suspecting this lesion in any sternoclavicular injury is stressed, early clinical examination being the most conclusive means of diagnosis. In some cases the diagnosis can be made definite only by the characteristic signs of reduction of the dislocation.

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The Covertebral Articulations and Cervical Foramen Encroachment

BY LEE A. HADLEY, M.D., SYRACUSE, NEW YORK

Occasional small cavities or gaps known as the covertebral articulations were originally described by von Luschka in 1858 as true synovial joints. They are situated posterolaterally between the lowermost five cervical vertebrae. Bony projections or lips variously termed the uncinate, costal, or lunate processes extend upward from the lateral margins of the upper surfaces of these vertebral bodies to articulate with the vertebral body above. Von Luschka called them intervertebral half joints. They are mentioned also as the uncovertebral joints [10], as the neurocentral joints, or as Luschka joints. While certain writers [1, 9] consider these to be true synovial joints, others [3, 7, 10] believe them to be only fissure spaces resulting from degeneration of disc substance. Of greater importance is the fact that normally the intervals between the upward projecting lips and the vertebrae above are only about one-third the thickness of the disc. Soon after degenerative thinning

of the disc begins, these projections impinge on the vertebrae above. As disc thinning continues, these processes are forced outward and laterally like the clinching of a horseshoe nail or a paper stapler. This results in the formation of laterally directed spurs or osteophytes. These are often shaped like the head of a bird. They project either toward the intervertebral foramen posterolaterally or more forward toward the vertebral artery in the transverse foramen (Figs. 2 and 3).

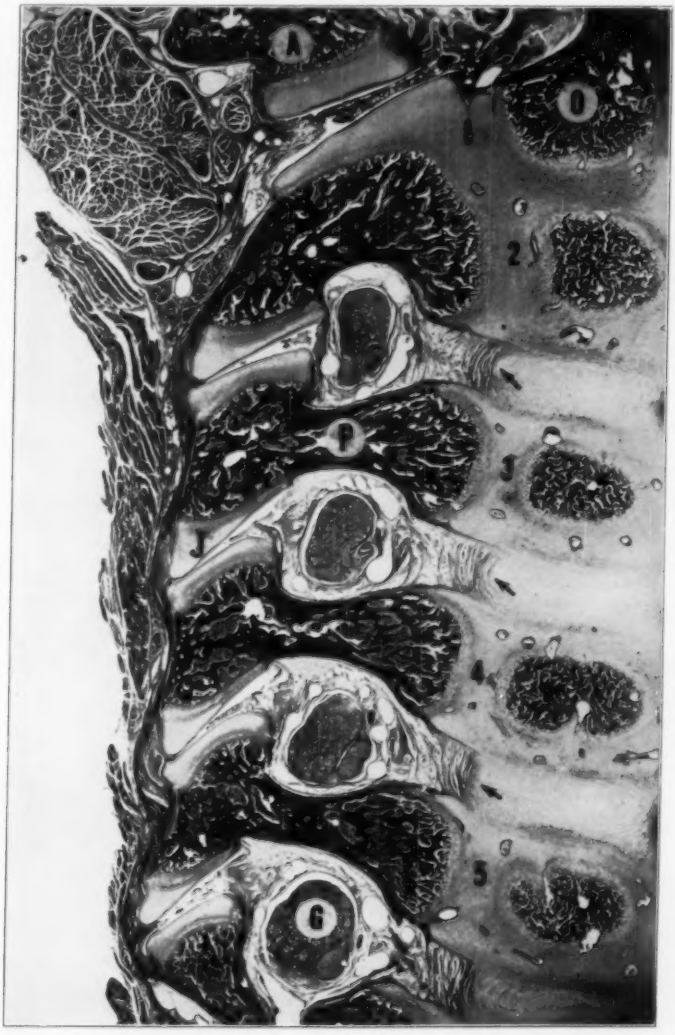

FIG. 1

Photomicrograph of cervical vertebrae from a newborn infant (× 6). Specimen was cut 45 degrees to the sagittal plane. Included are the second through the fifth cervical vertebrae with their pedicles (*P*), the intervertebral foramina, and the already completely formed posterior joints (*J*). At the sites of the posterolateral covertebral joints the vertebral bodies are connected by columns of dense fibrous tissue separated by many small blood vessels arising from the intervertebral foramina (arrows). This observation would seem to support the contention that these articulations are not true joints. At this age, the vertebral bodies are largely cartilage with many blood vessels and small ossification centers. The pedicles, however, are almost completely ossified. Within the foramen surrounding the larger sensory ganglion (*G*) and the smaller motor root below it is a loose cushion space containing many large blood vessels. The second cervical vertebra shows an ossification center for the odontoid process (*O*). A part of the atlas is seen at the upper margin of the section (*A*).

FIG. 2

Fig. 2, *A*: Transverse section from the cervical spine of a man, fifty-four years old, showing proximity of the uncinate processes to the undersurfaces of the supra-adjacent vertebrae. Compare this interval with the thickness of the normal disc.

Fig. 2, *B*: Section from the cervical spine of a woman, eighty-nine years old. Impingement is just beginning in the upper cervical region, while advanced degeneration has involved the lower three cervical discs with eburnation of the adjacent bone surfaces. Beak-like osteophytes have developed laterally as a result of the posterolateral intervertebral impingement.

Fig. 2, *C*: Oblique section from the cervical spine of a man, eighty-one years old, showing normal intervertebral foramina above; the lower foramina are encroached upon by osteophyte spurs projecting posterolaterally from the covertebral articulations

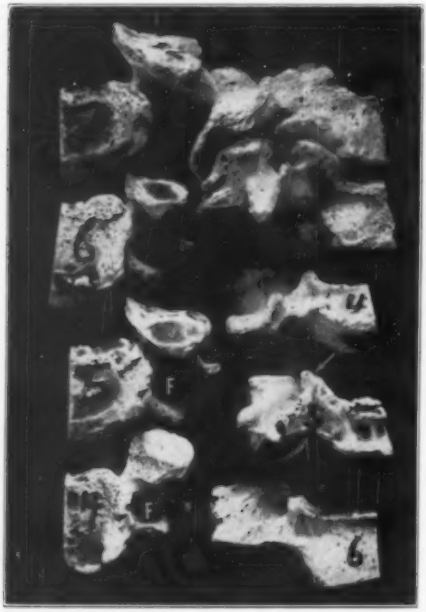

FIG. 3

FIG. 4

Fig. 3: A group of cervical half vertebrae. Those on the left are from a man seventy-three years old and are seen from above. Flange-like spurs project laterally and backward. The vertebrae numbered five and six show intervertebral foramenal encroachment (black arrows). Pulsation of the vertebral artery caused a notching of the spur opposite the transverse-process foramen, *F*, of the vertebrae numbered four and five (arrow heads). Those specimens on the right, below, are from a man seventy-six years old and show the upward projection of the uncinate processes (white arrow). The two half vertebrae at the top on the right are from a third specimen and demonstrate beautifully the large impinging posterolateral vertebral osteophytes.

Fig. 4: Section on the left is from the same specimen as that in Fig. 2, *A*. The discs show degenerative fissures which, laterally, might be interpreted as covertebral joint spaces. The vertebral artery has been coated with barium paste. The specimen on the right, cut at 45 degrees to the sagittal plane, shows the vertebral artery as it ascends in its canal and then abruptly turns posteriorly to penetrate the second transverse process (arrow head). A vertebral osteophyte projecting outward from the fifth disc has produced a sharp angulation of the artery (arrow). This common anatomical finding must exert some pressure upon the nerve fibers accompanying the artery.

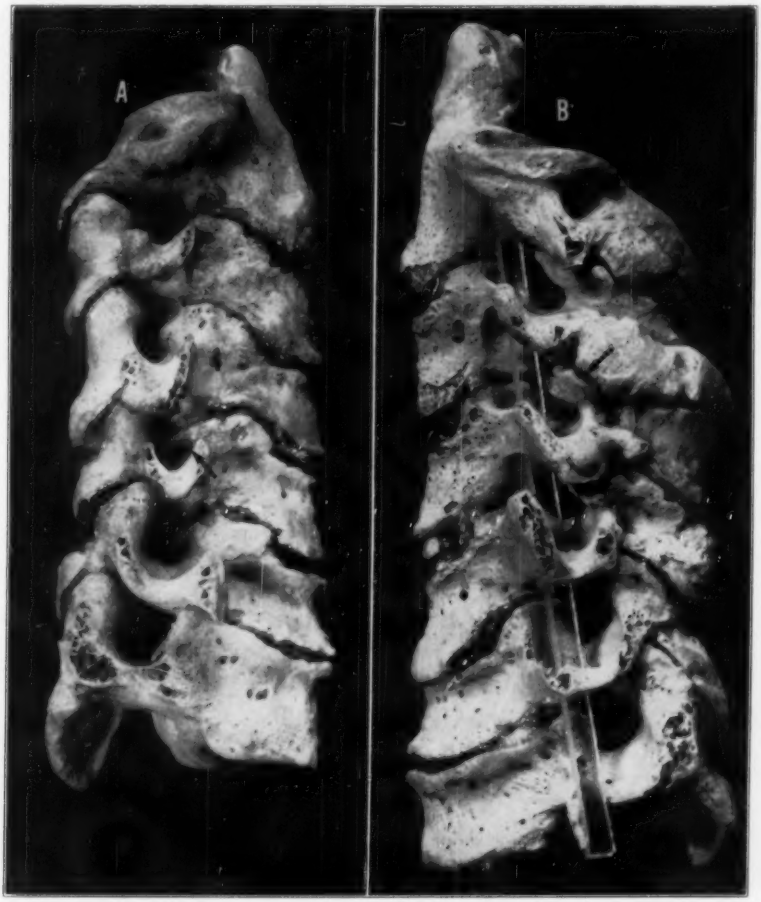

FIG. 5

Fig. 5, *A*: Right side of the cervical spine from a man seventy-eight years old, showing covertebral spur encroachment anterior to the third and especially the fourth intervertebral foramina (arrow). The other foramina are essentially normal.

Fig. 5, *B*: Left side of the cervical spine from a woman, sixty-four years old, showing arthrotic hyperplasia of the third posterior articulation with impingement beneath the transverse process of the vertebra next above and encroachment upon the intervertebral foramen from behind (arrow). A plastic rod in the transverse foramina indicates the position of the vertebral artery. This courses immediately anterior to and in direct contact with the cervical-nerve roots.

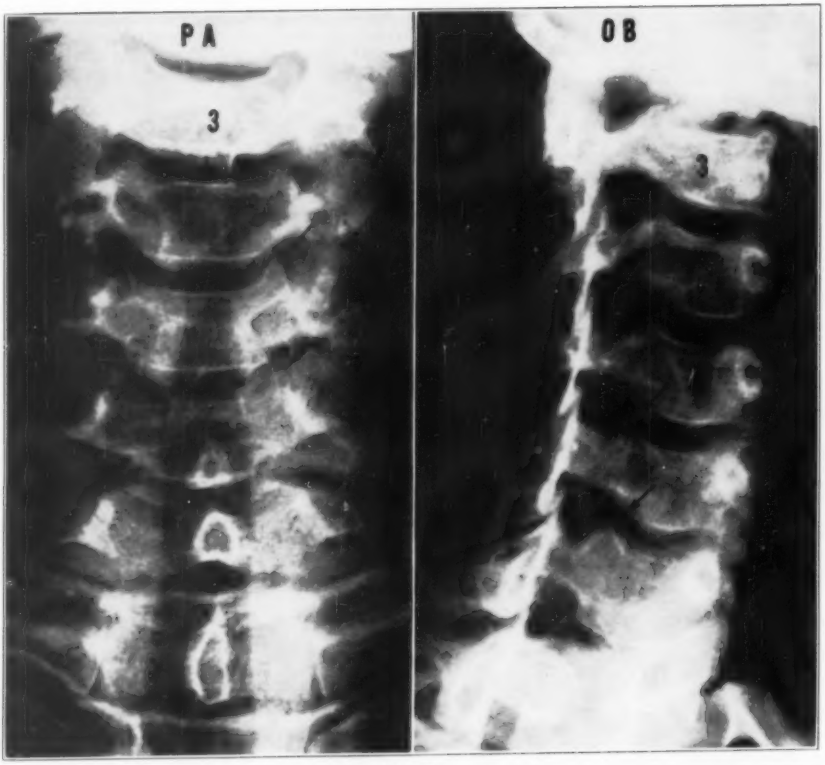

FIG. 6

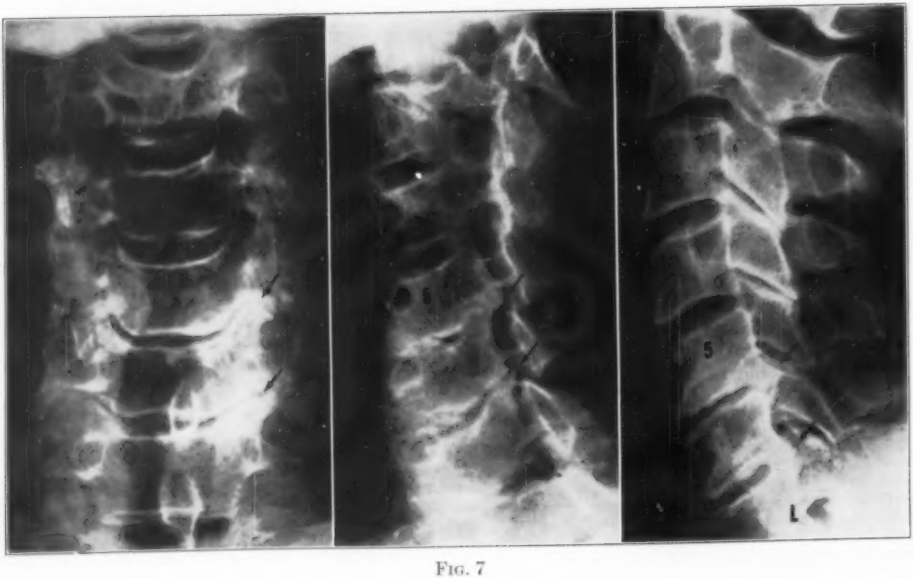

FIG. 7

Fig. 6: Postero-anterior and 45-degree oblique roentgenograms of the normal cervical spine of a woman thirty-six years old. By aligning the central beam of the x-ray with the occiput and under surface of the mandible, all of the cervical discs can be visualized with the covertebral articulations at each side. In the 45-degree oblique view one sees the normal intervertebral foramina with the adjacent covertebral articulations. Arrows indicate these joints in both projections.

Fig. 7: Roentgenograms of the cervical spine of a man sixty-one years old, showing advanced degeneration of the fifth and sixth cervical discs with impingement, eburnation, and beak-like covertebral spur formation (arrows). There is no thinning of the second, third, and fourth discs. The left oblique roentgenogram (middle) shows covertebral encroachment upon the fifth and sixth intervertebral foramina (arrows). The lateral roentgenogram (right) shows linear shadows crossing the fifth and sixth vertebral bodies. These are the projections of the cleavage plane along the upper surface of the covertebral osteophytes. They should not be mistaken for fracture lines following trauma. Backward projection of the covertebral osteophytes (arrows) simulate the bulging of the disc substance into the spinal canal but are located laterally at the foramina (see the oblique roentgenogram).

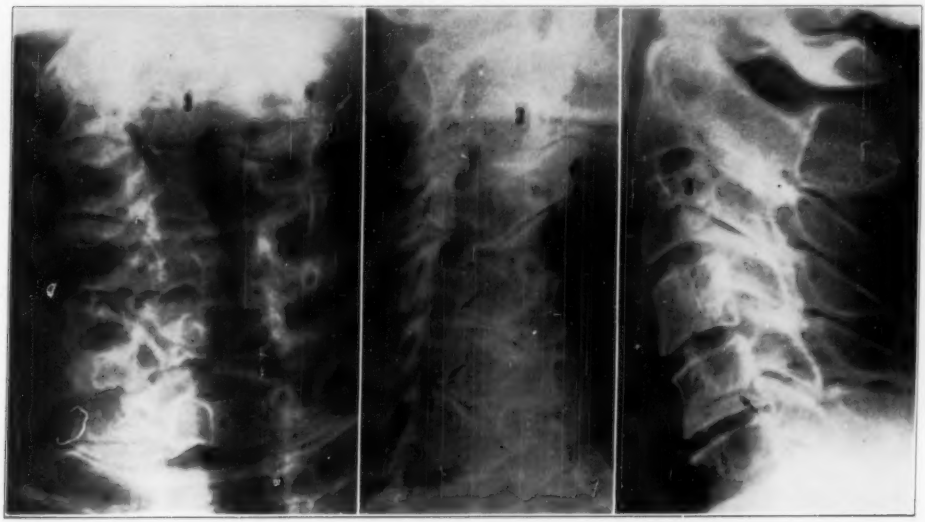

FIG. 8

Roentgenograms of the cervical spine of a man sixty years old with limited neck movement and pain referred to the right shoulder. This patient had osteophytes of the posterior articulation with bone encroachment upon the corresponding intervertebral foramina from behind (white arrows). In the lower cervical region, vertebral margin spurs (black arrows) are producing foramen encroachment anteriorly. In the lateral roentgenogram (right) one sees the hyperplastic posterior articular process impinging against the under surface of the third transverse process (white arrow). This curvilinear shadow may at times resemble the lateral projection of the impinging vertebral margin spur as seen overlying the fifth cervical body beneath (black arrow). In this patient there were co-existing the two types of foramen encroachment.

The vertebral artery and the accompanying sympathetic nerves ascend through the aligned foramina in the transverse processes in front of the various cervical-nerve roots. These sympathetic fibers, known as the posterior cervical sympathetic plexus, accompany the vertebral artery upward through the foramen magnum and pass along the basilar artery to the circle of Willis[1,8]. Vertebral-body marginal osteophytes projecting posterolaterally impinge upon the vertebral artery and upon its accompanying sympathetic-nerve fibers. This impingement may result in angulation of the artery. Degenerative shortening of the cervical spine may cause some tortuosity of the vertebral artery. These anatomical changes are clearly demonstrated by dissection and microscopic examination (Fig. 4).

Degenerative thinning of the disc also results in a straightening of the normal cervical curve or a telescoping of the posterior joints. With telescoping, the uppermost articular processes tend to subluxate backward and downward upon the opposing surfaces below. Bone-spur formation is stimulated about the margins of these articular surfaces. This telescoping and spur formation may at times be actually sufficient to produce an impinge-

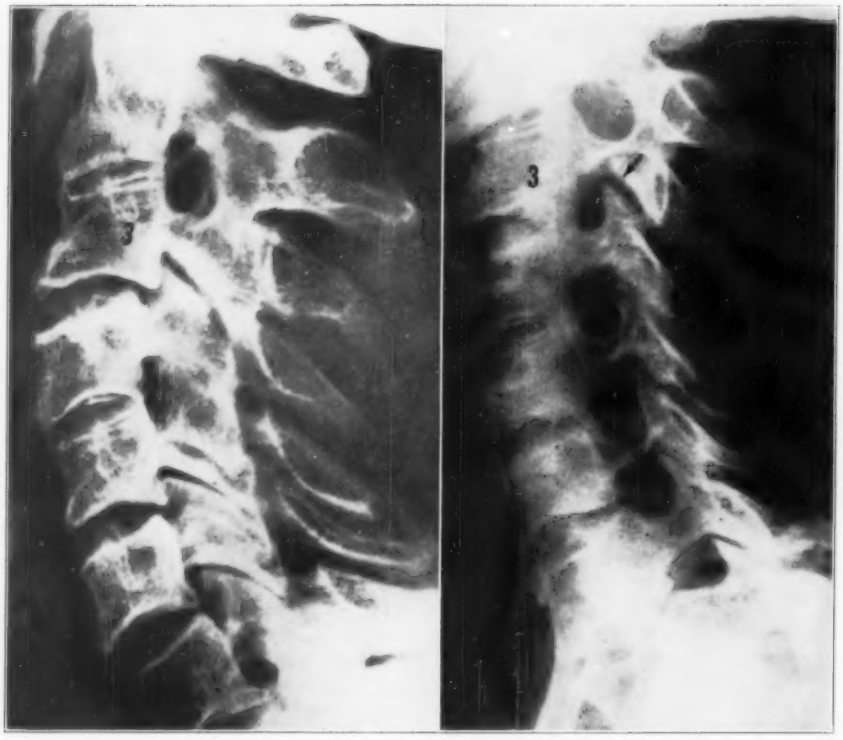

FIG. 9

A man, forty-nine years old, had non-segmentation at the level of the second and third cervical vertebrae and backward displacement of the third cervical vertebra on the fourth. This subluxation caused the fourth superior articular process to be thrust forward encroaching upon the intervertebral foramina (arrow). Compare the adjacent normal foramina as seen in the left oblique projection on the right.

ment of a superior articular process against the undersurface of the transverse process above it. Such a condition may likewise result in pressure of the spur against the vertebral artery or encroachment upon the intervertebral foramen (Fig. 5, *B*).

Roentgenograms made in three planes are essential. The postero-anterior projection is made with the patient lying face down upon the Bucky table and with the forehead supported by a small sandbag. The central ray is aligned with the occiput and the undersurface of the mandible. By means of this technique all of the cervical discs and covertebral articulations can be visualized (Fig. 6, *PA*). If impingements of the posterior articulations beneath the transverse processes are present, they are seen laterally in this roentgenogram.

In the lateral roentgenogram advanced covertebral osteophytic impingements may be visualized as lines crossing the vertebral body in the anterior posterior direction. These must not be mistaken for fracture lines (Fig. 7). A somewhat similar line or shadow may be cast by an impingement of the superior articular process beneath the transverse process. Differentiation between these two is made by the postero-anterior projection. In the lateral roentgenogram also, one may visualize a projection backward of the posterolateral covertebral osteophytes. This has somewhat the appearance of disc substance bulging backward into the spinal canal, but it is directed more laterally toward the intervertebral foramen (Fig. 7). Occasionally in the lateral roentgenogram a vertebra is seen to be subluxated backward on the one below. This is a cause of intervertebral-foramen encroachment (Fig. 9).

The oblique projection is made with the patient sitting upright, the sagittal plane

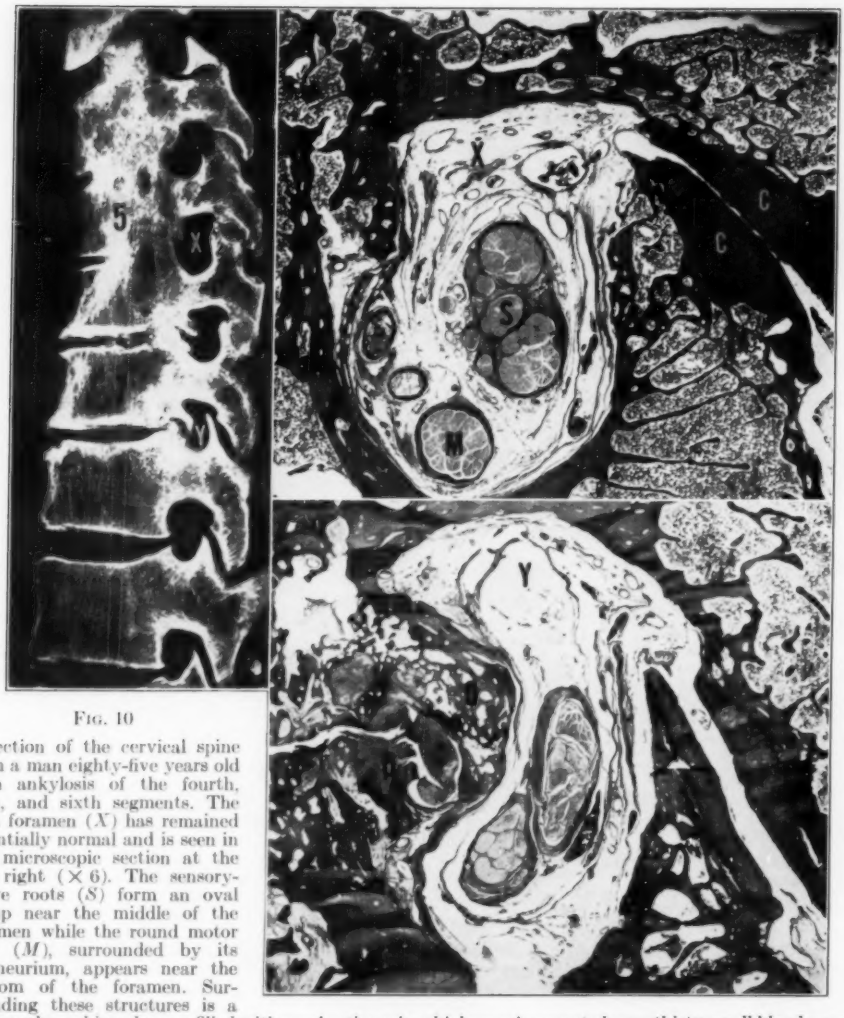

FIG. 10

Section of the cervical spine from a man eighty-five years old with ankylosis of the fourth, fifth, and sixth segments. The fifth foramen (*X*) has remained essentially normal and is seen in the microscopic section at the top right (× 6). The sensory-nerve roots (*S*) form an oval group near the middle of the foramen while the round motor root (*M*), surrounded by its perineurium, appears near the bottom of the foramen. Surrounding these structures is a generously cushioned space filled with areolar tissue in which may be counted over thirty small blood vessels. On the extreme right are the well preserved cartilage surfaces of the posterior articulation (*C*). The seventh cervical foramen (*Y*) (bottom right) shows encroachment by the vertebral-body marginal osteophytes (*O*). Between these is entrapped a small oval mass of extruded disc substance (*D*). As seen here, and again in the roentgenogram, this small mass of disc is almost completely surrounded by bone. Herniations of the cervical disc have been repeatedly described as causing foramen encroachment in this region. In our experience it is rather the protrusion of the vertebral osteophytes which produces this constriction. The nerves in this foramen are somewhat flattened and show thickening of the perineurium. (Reproduced by permission from L. A. Hadley, *The Spine*. Springfield, Illinois, Charles C. Thomas, 1956.)

being at 45 degrees to that of the film. The central ray is directed 10 degrees downward and is centered from behind on the mid-cervical region. This will show all of the cervical foramina as they normally appear in a curved alignment (Fig. 6, *OB*).

With good oblique roentgenograms, one is able to visualize encroachment of the intervertebral foramina—anteromedially by vertebral-body marginal spurs and posterolaterally by spur formation from the superior bony margins of the posterior articulations. Also, when backward displacement of a vertebra has occurred, an encroachment on the foramen by the underlying superior articular process will be evident (Figs. 7, 8, and 9).

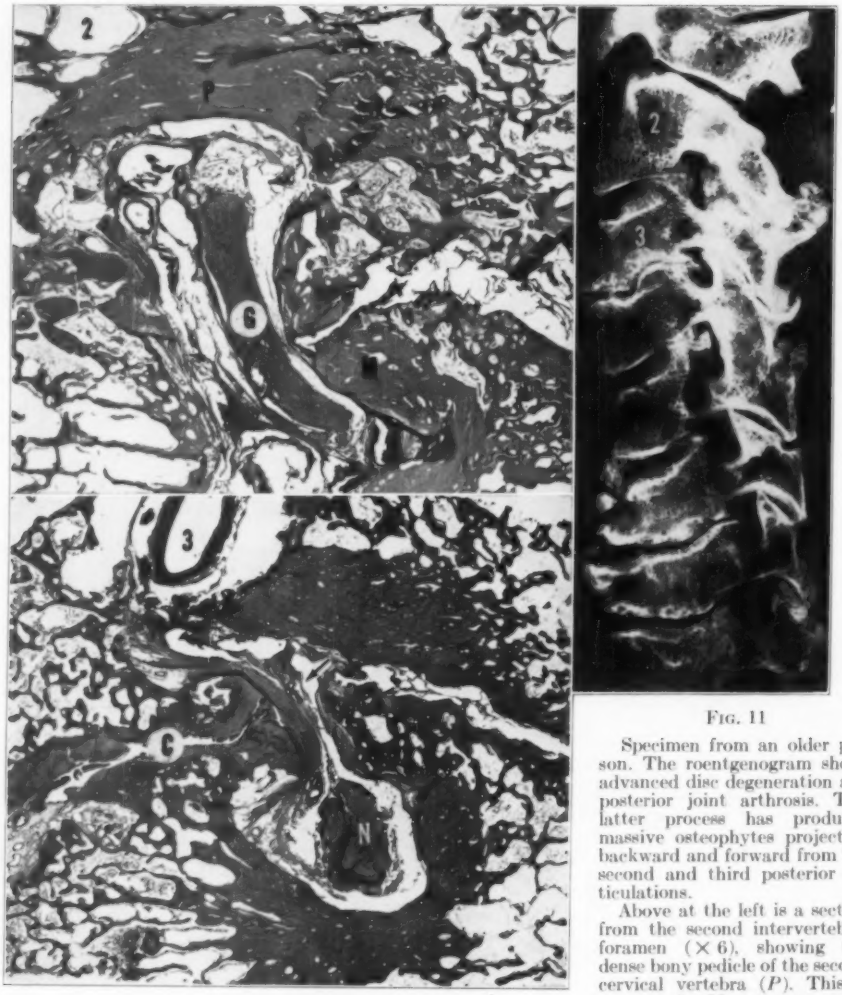

FIG. 11

Specimen from an older person. The roentgenogram shows advanced disc degeneration and posterior joint arthrosis. This latter process has produced massive osteophytes projecting backward and forward from the second and third posterior articulations.

Above at the left is a section from the second intervertebral foramen (× 6), showing the dense bony pedicle of the second cervical vertebra (*P*). This is an example of foramen encroachment by a rounded bony mass (*M*) projecting forward from the posterior joint. The normally round or oval ganglion (*G*) has become flattened into a ribbon-like structure, slightly curved on section.

The section below is from the third cervical foramen (× 6). There is marked encroachment on this foramen by impinging osteophytes projecting backward above and below the badly degenerated intervertebral disc (*C*). A thickened section of the longitudinal ligament has been pushed backward into the upper part of the foramen by these spurs (arrow). Also a spur has become thrust forward into the upper portion of the foramen from the posterior articulation. Lastly, from thinning of the disc, the third and fourth pedicles are closer than normal so that the cephalad-caudad diameter of the foramen is decreased. The nerve root (*N*) is distorted and much smaller than normal. It had become crowded to the floor of the foramen and dense fibrosis of the perineurium, especially of its inferior portion, developed. Many of the blood vessels have disappeared from the foramen. To appreciate the constriction of this opening, note that it is shown at the same magnification as the foramina in Fig. 10. Under high power one can identify new bone being laid down in the fibrocartilage covering the osteophytes. Such fibrocartilage and the thickened ligamentous tissue cause the foramen to be much smaller than it appears on the roentgenogram. (Reproduced by permission from L. A. Hadley, *The Spine*. Springfield, Illinois, Charles C. Thomas, 1956.)

A normal intervertebral foramen provides an ample cushion space about the motor and sensory-nerve roots. Only about one-fourth of the space is occupied by these structures, which are surrounded by areolar tissue and many small blood vessels. As a result of foramen encroachment, the nerve roots may become distorted and displaced. A fibrous

perineuritis or adhesions within the foramen are easily demonstrated by anatomical study (Figs. 10 and 11).

Bony encroachment of the intervertebral foramen may be present without symptoms at the time of examination, or symptoms of root pressure may be present without roentgenographic evidence of foramen encroachment. Other factors such as oedema, congestion of the many small blood vessels, and fibrosis may be partly responsible. If present, the symptoms are of three types: local, referred, and sympathetic. Local pain, tenderness to deep pressure upon the sides of the neck, muscle spasm, and limitation of motion may be encountered in patients with foramen encroachment. When root pressure is present, patients may suffer from the pain of radiculitis referred to the occiput, shoulder, arm, or hand and corresponding with the distribution of the involved nerve root. The confirmatory Déjerine sign of radiculitis, that is, pain exaggerated by increased intraspinal pressure, is elicited by coughing, sneezing, or pressure brought to bear on the region. Pain may be increased if the foramen is additionally constricted by rotating or flexing the neck backward or toward the involved side. Diminished reflexes with weakness or atrophy of forearm and hand muscles appear later.

Symptoms resulting from pressure upon the vertebral sympathetic plexus are said to result, in part, from vasoconstriction of the bulbopontine vessels. They constitute a most bizarre and confusing clinical picture, which has been described as the Barré-Lieou syndrome [4, 11]. Some of the complaints are: tinnitus and diminished hearing, spots before the eyes, mydriasis, recurrent corneal ulceration and lessened pupillary reflexes, various types of pain in the head, face, throat, ears, or sinuses, sensory disturbances of the pharynx, aphonia, vertigo, sweating, flushing lacrimation, and salivation, to mention but a few.

SUMMARY

Covertebral osteophytes, secondary to disc degeneration, may impinge either upon the vertebral artery and its surrounding sympathetic plexus or more posteriorly upon the intervertebral foramen.

In the posterior cervical articulations, secondary to degenerative processes, osteophytes may likewise develop which impinge upon the vertebral artery or encroach upon the intervertebral foramen.

Such a foramen, encroached upon by either osteophytes or backward slipping of a vertebra, may show microscopic changes involving the compressed nerve root.

NOTE: These studies were assisted by the Departments of Anatomy and Photography, New York State School of Medicine, Syracuse, New York.

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DISCUSSION

IMPINGEMENT EXOSTOSIS

(*Continued from page 852*)

terior portion of the ankle and of loss of ability to drive, which had resulted in his being transferred from the backfield to the line. He had a very large loose body which had its origin in the anterior margin of the tibia.

[The sixth and seventh slides showed the condition in the same boy at the time of surgery.] There was a wedge of osteochondral reaction along the tibia, most marked on the lateral side, and an area of notching which apparently was the site of the loose body. Over the neck of the talus, there was a very discrete exostosis just lateral to the mid-line. There was also some grooving in the articular cartilage of the talus caused by the opposing roughened margin of the tibia. Considerable change was present along the anterior margin of the fibula and the synovial membrane was thickened. The shelving of the tibia was within the articular capsule, a finding which supports Dr. O'Donoghue's theory of etiology.

[Slide eight showed a roentgenogram of a fifty-year-old man who had a history of trauma to the ankle in past years; this patient had done manual labor and had participated in athletics.] In this case the loose bodies and the shelving along the tibia were removed, the approach used being almost identical with that described by Dr. O'Donoghue.

[Slide nine showed the same patient three years later.] There has been no recurrence of the exostosis or loose bodies and the patient has remained symptom-free.

I feel that our management of this condition has perhaps been influenced by lack of appreciation of the significance of the findings. Certainly, we have reserved surgery for only those patients with advanced changes.

DR. O'DONOGHUE (CLOSING): There are really two parts to this paper: first, a description of a remedial operation for symptomatic exostoses, and, second, a study of the frequency of this type of exostosis in athletes as opposed to its frequency in non-athletes. In the frequency study, we questioned the subjects as to their complaints and determined that among the athletes having no spurring, 3 per cent had some complaint in front of the ankle, while among those having either talar or tibial exostoses 10 per cent had complaints and among those having both talar and tibial spurring 12 per cent had complaints. This would seem to indicate, as previously suggested, that the combination of exostoses in both areas causes the most trouble. Strangely enough, in the non-athletic group, the only subject with a complaint was one who did not have any spurring. This, of course, is not statistically important.

We are quite interested in the prevention of this condition since we know it is sometimes symptomatic. We have definitely reduced the number of knee injuries by prohibiting the exercise known as deep knee bends, as a result of this exercise the posterior horn of the semilunar cartilage may become overmobilized. It may be that there is some way of restricting forcible dorsiflexion of the ankle, which I think accounts for the spurring.

In some cases, the exostoses extend pretty well around the ankle joint. I have noticed this more in non-athletes than in athletes, and I think that the exostoses in these cases are often accompanied by traumatic arthritis of the joint, with the result that the etiology in these cases is different from that in the more usual case, although the pathology may be similar.

The operation is not technically difficult and offers a good chance for complete cure if done meticulously. In regard to the question of postoperative care, the splint referred to is a plaster stirrup splint which is worn for ten days, it consists of a posterior splint and a lateral sugar tong. After this splint has been removed and the stitches have been taken out, a light-weight walking cast is applied and worn for another ten days. By the end of three weeks, all fixation is removed and the patient is urged to rapidly increase his activity. Rehabilitation is not ordinarily a problem in the athlete since he is only too eager to get back into condition.

Paralytic Valgus Deformity of the Ankle

Replacement of the Paralyzed Tibialis Posterior by the Peronaeus Longus

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From the Orthopaedic Department, Beilinson Hospital, Petach-Tiquah

The epidemic of poliomyelitis in Israel from 1950 to 1953 affected children one to three years old principally. Impaired muscle balance resulted in the deformity of many of these children, and as is to be expected, many of these were paralytic valgus deformities or calcaneovalgus deformities of the ankle.

Since stabilization procedures were not considered immediately advisable in these small children, restoration of muscle balance seemed the most desirable method of treatment [9]. In an earlier publication one of the authors showed that tendon transfer is a safe procedure in children even as young as three to five years of age if care is taken to attach the tendon firmly to the bone [6]. It was found that a tendon guided through a bone canal and sutured to the skin by means of a Bunnell pull-out wire rarely failed to function normally after removal of the plaster immobilization. On the basis of this experience, redistribution of active muscles for the correction of valgus deformity was undertaken in young poliomyelitic patients.

MUSCLE REDISTRIBUTION

Valgus deformity of the ankle may be static when muscle power is normal or nearly normal. Dynamic valgus deformity, however, is caused by paresis or paralysis of the invertor muscles, while their antagonists continue to function. Dynamic deformity is progressive and cannot be corrected by braces of any description. The deformity becomes fixed by secondary bone changes which take place during the years of growth.

Dynamic deformity can be corrected, muscle balance can be restored, and bone changes can be prevented only if adequate muscle redistribution is carried out during the first years of the residual effects of the disease. The reconstruction must be based on accurate evaluation of the residual muscle power and on a proper clinical examination of the extremity, with and without weight-bearing. The weakness and the strength of the opposing muscle groups must be carefully evaluated, and calculation must be made of the approximate amount of muscle power required of the transfer.

FUNCTIONAL ANATOMY OF DYNAMIC DEFORMITY

Dynamic deformity of the ankle joint is caused by the constant pull of muscles whose antagonists are weakened or paralyzed. This pull affects the two joints of the hind part of the foot and holds them in faulty position, resulting in deformity. The joints of the hind part of the foot each consist of two units, the talotibial joint and the subtalar joint, and are controlled by four muscle groups. The muscles in each of these four groups insert near the joints they activate and supply the primary motor power of their respective joints [4, 13]. Other muscle tendons pass these joints proceeding to their insertion near a joint which they will activate. For example, the extensor digitorum longus passes the talotibial joint, the mid-tarsal joint, and the small joints of the toes, and inserts into the second and third phalanges of the four lesser toes. This muscle chiefly activates the toes, as long as the primary muscles are able to stabilize the talotibial joint and the subtalar joint. If there is loss of power of the primary motors, the extensor digitorum longus will act on the ankle joints, but its action is limited and results in further deformity—in this example, hyperextension of the toes [5, 14]. The muscles inserting beyond the bones of the ankle joints are the auxiliary motors of the ankle joints (Table I).

TABLE I

MOTOR MUSCLES AT THE ANKLE JOINTS

Movement	Primary Motor Muscle	Auxiliary Motor Muscles
Dorsiflexion	Tibialis anterior	Extensor hallucis longus Extensor digitorum longus
Plantar flexion	Triceps surae	Tibialis posterior Flexor digitorum longus Flexor hallucis longus
Inversion	Tibialis posterior Tibialis anterior	Flexor digitorum longus Flexor hallucis longus
Eversion	Peronaeus longus Peronaeus brevis	Extensor digitorum longus

There are three causes of dynamic valgus deformity: (1) paralysis of the tibialis anterior, (2) paralysis of the tibialis posterior, and (3) paralysis of both invertors.

Paralysis of the tibialis anterior, only, usually causes moderate valgus deformity. The deformity is more pronounced during dorsiflexion and may disappear during plantar flexion. Dorsiflexion is achieved by the toe extensors, the extensor hallucis longus functioning first, causing hyperextension of the big toe with the interphalangeal joint remaining flexed. During dorsiflexion the extensor digitorum longus pulls the foot into valgus position because of its lateral anchorage to the cuboid and to the outer toes. The eversion caused by the extensor digitorum longus muscle during dorsiflexion is very strong and is comparable to the pull of the peroneals.

Paralysis of the tibialis posterior causes severe valgoplanus deformity. Normally, this muscle is responsible for inversion during plantar flexion. Most of the functions of the foot are performed during plantar flexion, that is, when walking on tiptoe, when pressing the foot against the floor, and when lifting the heel during walking. Loss of function in this muscle severely impairs the normal performance of foot movements. The auxiliary muscles of the tibialis posterior, that is, the long flexors of the five toes, have little power to counteract valgus deformity because of their lateral position. Moreover, the tibialis posterior is the principal support of the arch of the foot as its tendon divides and inserts into the navicular and the metatarsal bones. Loss of this support causes the arch to collapse, increasing the valgus deformity, and resulting in valgoplanus deformity.

The loss of both invertors leads to extreme deformity. A convex pes planus is often the final result, the head of the talus protruding at the plantar surface. This deformity is similar to congenital convex pes planus.

All three types of invertor loss may be associated with paralysis or weakness of the triceps surae muscle, thereby adding calcaneal deformity to the already existing valgus deformity.

CONSIDERATIONS IN PLANNING OPERATIVE CORRECTION

In order to restore muscle balance in valgus deformity, the type of deformity must be identified, the power of the different muscles must be evaluated by means of the muscle-power chart (Table II), and the motor power of the remaining healthy invertor muscles must be compared with the power of the evertors. The purpose of tendon transfer is to establish the same amount of power in both of these muscle groups.

For example, if the tibialis anterior power is 4 and the tibialis posterior power is 0, the invertor muscle motor power will be 4. If the extensor digitorum longus power is 4 and the peronaei power is 5, the evertor muscle power will be 9.

TABLE II*

RECONSTRUCTION IN TWELVE PATIENTS OF THE TIBIALIS ANTERIOR BY TRANSFER OF PERONAEUS LONGUS ACCORDING TO THE METHOD OF MAYER-BIESALSKI, AND IN SEVEN PATIENTS BY TRANSFER OF THE EXTENSOR DIGITORUM LONGUS

Case No.	Before Operation: Tibialis Posterior Power	Before Operation: Tibialis Anterior Power	After Operation: New Tibialis Anterior Power	Result	Remarks
103	3	2	4	Good alignment	
58	3	0	4	Good alignment	
43	3	0	4	Good alignment	
54	4	0	4	Good alignment	
37	3	1	3	Good alignment	
68	3	1	4	Mild valgus	
275	3	0	4	Good alignment	
73	3	2	4	Mild valgus	
211	3	2	4	Good alignment	
75	3	1	4	Good alignment	
107	0	2	4	Severe valgo-abductus	
90	0	0	3	Valgus	
204	0	0	4	Calcaneovalgus	Weak triceps surae
64	0	3	4	Calcaneovalgus	Weak triceps surae
102	0	0	5	Calcaneovalgus	Weak triceps surae
151	0	0	4	Calcaneovalgus	Weak triceps surae
195	0	0	4	Valgus	Weak triceps surae
56	0	0	4	Calcaneovalgus	Weak triceps surae
89	0	0	4	Calcaneovalgus	Weak triceps surae

Note: This operation always failed when both the tibialis anterior and the tibialis posterior were paralyzed.

* MUSCLE MOTOR POWER GRADING SCALE

Total paralysis	0
Trace of power	1
Movement	2
Movement against gravity	3
Good muscle power	4
Strong muscle power	5

There are two methods by which this difference in muscle power may be corrected. Invertor power may be added by use of an uninvolved muscle—for example, the flexor longus digitorum; or eversion power may be diminished by the elimination of one of the evertor muscles, which, transferred to the inner side of the foot, may strengthen inversion—for example, the transference of the peronaeus longus to the tibialis posterior. In each instance, the inversion-eversion balance expected after the transfer must be determined. This is done by considering the different muscles which are available for the correction.

The first method of treatment in this example could be the transfer of the flexor digitorum profundus to the tibialis posterior. If the tibialis anterior power is 4 and the new tibialis posterior power is 3, the restored invertor motor power will be 7. If the extensor digitorum longus power is 4 and the peronaei power is 5, the evertor motor power remains 9. The second method could be a transfer of the peronaeus longus to the tibialis posterior. If the present tibialis anterior power is 4 and the new tibialis posterior power is 4, the restored invertor motor power is 8. If the extensor digitorum longus power is 4 and the residual peronaeus power is 4, the evertor motor power will be 8.

In preoperative planning, the second transfer will be chosen to correct the deformity. Frequently there are several muscles suitable for the intended transfer and it is often

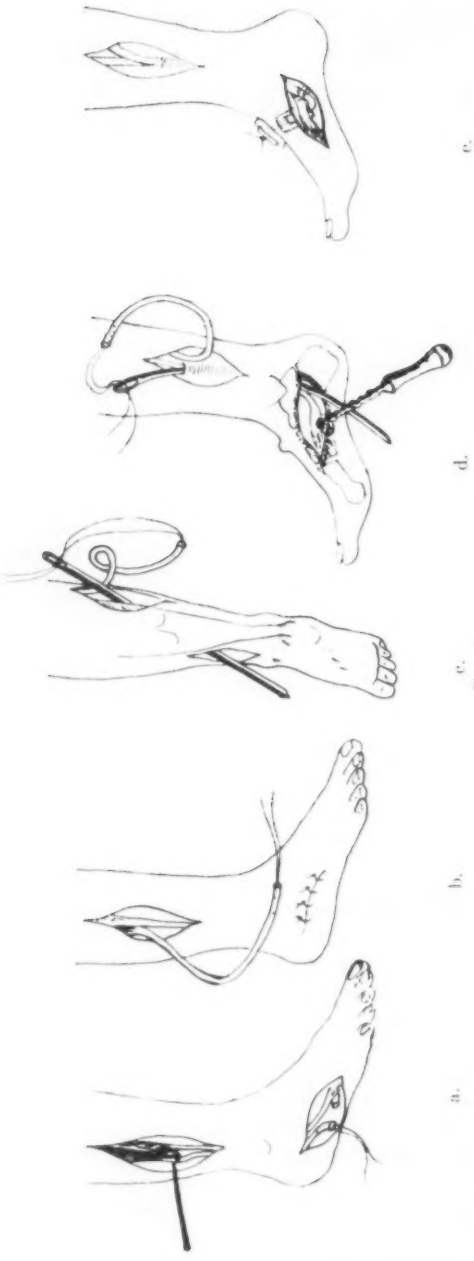

Fig. 1

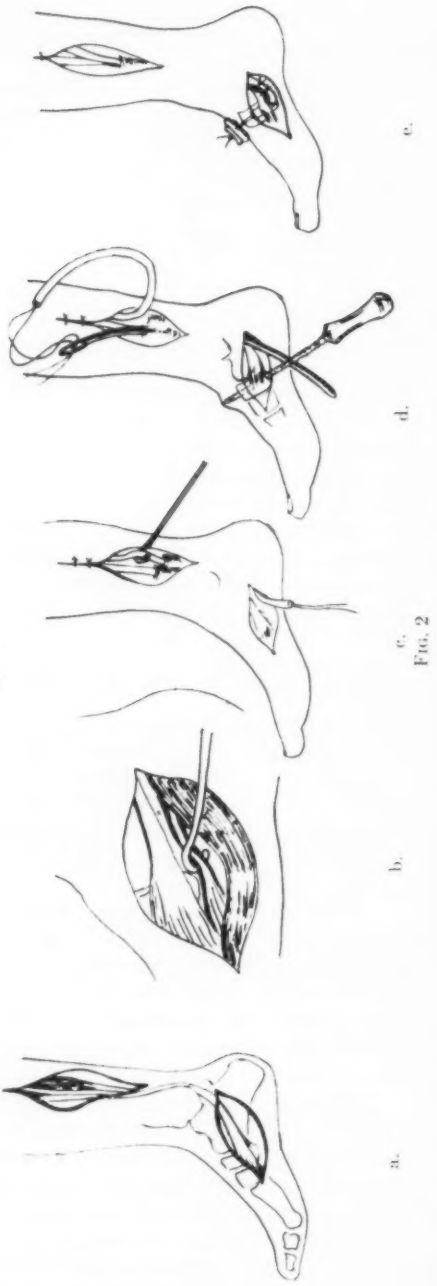

Fig. 2

Fig. 1: Drawing of the transfer of a peronaeus longus tendon to replace a paralyzed tibialis posterior muscle.

a. First incision at the lateral plane of the lower portion of the leg. Inspection of muscle fibers of the peronaeus longus muscle. Second incision at the outer border of the foot. Dissection of the peronaeus longus tendon. The tendon is cut close to its entrance at the sole of the foot. The distal tendon stump may be sutured to the peronaeus brevis tendon.

b. The tendon is withdrawn at the first incision.

c. Third incision above and behind the medial malleolus. The tendon of the peronaeus longus is passed between the deep flexor muscles and the Achilles tendon and emerges at the medial aspect of the lower portion of the leg.

d. The tendon sheath of the tibialis posterior muscle is opened above the malleolus. A fourth incision is made at the medial side of the foot centering at the tubercle of the navicular. The plantar fascia is incised and the soft tissues dissected from the tarsal bones, freeing the tibialis posterior tendon and the navicular. A bone canal is curetted through the navicular starting laterally from the tubercle at the lower plane of the bone and directed obliquely to the dorsal side of the mid-foot. The tendon is passed through the sheath of the tibialis posterior.

e. The tendon is inserted in the prepared bone canal and sutured to the skin of the dorsal portion of the mid-foot by a Bunnell pull-out wire suture.

Fig. 2. Drawing of the transfer of the flexor digitorum longus muscle to replace a paralyzed tibialis posterior muscle.

a. Incision at the medial side of the lower portion of the leg. The tendon and muscle bellies of the tibialis posterior and flexor digitorum longus muscles are freed and the muscle fibers are inspected. Second incision at the medial side of the foot, centering at the tubercle of the navicular. The plantar fascia is incised and the soft tissues are dissected from the tarsal bones.

b. The tendons of the tibialis posterior and the flexor digitorum longus are freed, and the latter tendon is cut deep near the sole of the foot.

c. The tendon is redrawn at the first incision.

d. The tendon is passed through the tendon sheath of the tibialis posterior, emerging together with the latter at the medial portion of the sole. A bone canal is curetted laterally from the navicular tubercle, from the lower plane of this bone to the dorsal portion of the mid-foot.

e. The tendon is passed through this canal and sutured to the skin of the dorsal portion of the mid-foot by a Bunnell pull-out wire suture.

difficult to decide which one will result in the most effective motor power. Therefore, a description of each one of these muscles is expedient:

1. *Extensor digitorum longus:* This muscle is a strong evertor and dorsiflexor which acts on the four lateral toes and, by its accessory tendon, peronaeus tertius, on the outer side of the foot. This muscle is particularly suited to replace the tibialis anterior. When the peronaei are not strong, the new muscle should be inserted in the mid-line of the dorsal portion of the mid-foot to function as a dorsiflexor only and to prevent overcorrection if the tibialis posterior muscle is normal.

2. *Peroneal muscles:* These are two strong everters, well suited for use as transfers. It is almost impossible to estimate their individual muscle power, but it is generally assumed that they function with equal power and they also grade alike. When separated, however, the power of these two muscles seems to increase. If their combined motor power is graded 5 before one of them is transferred, the remaining muscle generally has an eversion power of 4, and the transferred muscle, if the transfer has been successful, also grades 4. Sometimes, however, the two muscles prove to be unlike in power, this fact being recognized only after the transfer has been made and the two muscles are functioning separately. Thus, it is seen that preoperative grading of muscle power is only an estimate. To avoid error as much as possible, the bellies of both peroneal muscles should be inspected carefully before the tendon of one is separated from its insertion to be transferred. An alternative plan for the tendon transfer should be ready for use if, after the operation has begun, inspection of the muscle bellies should disclose a discrepancy between the preoperative grading and the color of the muscles.

3. *Extensor hallucis longus:* The muscle is well suited for use as a transfer. It may be transferred to the first metatarsal (the Jones operation [8]) to substitute for a tibialis anterior, and it may also be transferred backward (as in the Peabody operation [12]) to substitute for a tibialis posterior muscle.

4. *Flexor hallucis longus or flexor digitorum longus:* Both of these muscles are well suited to replace the tibialis posterior because of the proximity of their tendons to the tendon of the tibialis posterior muscle. In estimating their power, care should be taken to differentiate their functions from that of the short flexor. The long flexor tendons flex

FIG. 3-A

FIG. 3-B

Fig. 3-A: Case 10. Preoperative photograph of severe valgoplanus-abductus deformity resulting from paralysis of both tibiales.

Fig. 3-B: Sixteen months after surgery, July 1954, the peronaeus longus was transferred to replace the tibialis posterior. The alignment of the foot is nearly normal.

the distal interphalangeal joints; the short flexor tendons flex the proximal joints of the toes. Because of tendinous connections between the two long flexors which are found in some persons, the functions of these muscles may be reversed, and this variance from the normal may lead to erroneous preoperative planning. Therefore, the bellies of these muscles should be inspected as carefully as those of the peroneal muscles prior to the division of the tendon.

FIG. 4-A

SURGICAL CORRECTION OF VALGUS DEFORMITY

The technique of the operation to correct the muscle imbalance should be chosen according to the type of valgus deformity.

For the first type of muscle imbalance—paralysis of the tibialis anterior muscle—we used chiefly the method of Mayer and Biesalski[3, 10, 11], that is, the transfer of a peroneal muscle anteriorly to the first cuneiform. An alternative technique to this is the transfer of the extensor digitorum

FIG. 4-B

FIG. 4-C

Fig. 4-A: Case 16 (Table IV). Preoperative photograph of left foot in severe valgoplanus abductus position, the result of paralysis of both tibiales.

Figs. 4-B and 4-C: Twenty months after operation in February 1954. The flexor hallucis longus was transferred to replace the tibialis posterior.

FIG. 5-A

FIG. 5-B

Figs. 5-A and 5-B: Case 15. Preoperative photographs. Paralysis of both tibiales.

FIG. 5-C

FIG. 5-D

Figs. 5-C and 5-D: Eighteen months after surgery in October 1954. The flexor digitorum longus was substituted for the tibialis posterior. Three months later (January 1955), the extensor digitorum longus was substituted for the tibialis anterior. Normal alignment resulted.

longus to the first cuneiform or the Jones suspension operation with the extensor hallucis longus being used as transfer.

Before the importance of the tibialis posterior muscle was fully understood, we found that these operations produced good results when an active tibialis posterior was present. Failure was a common outcome, however, when the tibialis posterior was paralyzed (Table II).

We concluded that in type-two muscle imbalance, when only the tibialis posterior muscle is paralyzed, replacement is necessary, for apparently the paralysis of this muscle is the chief reason for paralytic valgus deformity. In the third type of muscle imbalance, paralysis of both tibialis muscles, we first replace the tibialis posterior and later, if necessary, the tibialis anterior.

When paralysis of the invertors accompanies weakness or paralysis of the triceps surae, it is often possible to combine replacement of the triceps surae with replacement of the invertors.

If there are not enough healthy muscles available for transfer, it will be necessary to eliminate the evertors, using them, for instance, to strengthen a weak triceps surae, thereby achieving negative invertor-evertor balance. Feet which have been subjected to this treatment often require some kind of stabilization.

The Grice procedure is successful in small children and it may be combined with the muscle-transfer operation.

FIG. 6-A

FIG. 6-B

Figs. 6-A and 6-B: Case 11. Preoperative photographs of calcaneovalgus deformity of the right ankle, resulting from paralysis of both tibiales and of the triceps surae.

FIG. 6-C

FIG. 6-D

Figs. 6-C and 6-D: Two months after operation in February 1954. The peronaeus longus muscle was used to replace the tibialis posterior. The peronaeus brevis, the flexor hallucis, and the flexor digitorum longus were used to strengthen the weak triceps surae. The new triceps surae graded 5 in power, the new tibialis posterior graded 4. Normal alignment resulted.

THE REPLACEMENT OF THE TIBIALIS POSTERIOR MUSCLE

In 1931, von Baeyer published a report of an operation for isolated paralysis of the tibialis posterior. In this procedure, the tendon of the peronaeus longus muscle is cut on the lateral side of the mid-foot near its insertion beneath the cuboid. The distal end is freed by blunt dissection and is passed through the sole of the foot to emerge at the medial side of the mid-foot, near the navicular. The proximal part of the tendon is passed between the Achilles tendon and the posterior aspect of the ankle to the medial malleolus, and is sutured, end to end, to the previously freed distal portion of the tendon.

We use a different technique which seems simpler and more efficient. It consists in transferring the tendon of a healthy, normally functioning muscle through the tendon sheath of the paralyzed tibialis posterior and inserting it into the navicular unimpeded by end-to-end suturing as done by von Baeyer. The transferred tendon glides smoothly through the tendon sheath and acts directly upon the apex of the longitudinal arch of the foot. For this procedure, we generally use the tendon of the peronaeus longus muscle.

A longitudinal incision five to eight centimeters long is made over the lateral aspect of the shaft of the fibula. The fascia of the peroneal muscles is incised and the muscles are inspected. Their color must confirm the preoperative grading in order to proceed with the transfer. A second incision is made over the lateral side of the mid-foot. The tendon

TABLE III

RECONSTRUCTION OF THE TIBIALIS POSTERIOR BY TRANSFER OF THE PERONAEUS LONGUS OR THE PERONAEUS BREVIS

	Preoperative Grading				Postoperative Grading						
Cases	Ext. Dig. Long.	Peron.	Tib. Ant.	Tib. Post.	Ext. Dig. Long.	Peron. Br.	Peron. Long.	Tib. Ant.	Tib. Post.	Result	Remarks
Five patients with normal tibialis anterior and medium valgoplanus deformity											
1.	0	5	4	0	0	4		4	3	Normal alignment	
2.	4	5	5	3	4	2		5	5	Varus deformity	Peronaeus brevis proved to be weak; was not controlled during operation.
3.	4	5	3	3	4	4		3	3	Mild valgus	Peronaeus longus was faulty; graded 5 preoperatively
4.	3	4	2	0	3	4		2	4	Normal	
5.	3	4	4	0	3		3	4	3	Normal	
Five patients with paralysis of both invertors and severe valgoplanus deformity											
6.	3	5	0	0	3	3		0	4	Normal	
7.	5	5	0	0	5	4		0	4	Medium valgoplanus deformity	Corrected later by reconstructing tibialis anterior
8.	3	4	0	0	3	3		0	4	Normal	
9.	4	4	0	0	4	4		0	4	Normal	
10.	0	3	0	0	0	3		0	4	Normal	
Four patients with calcaneovalgus deformity in whom tibialis posterior reconstruction was combined with triceps surae reconstruction. New triceps surae motor power was graded 4 or 5.											
11.	4	4	0	2	4			0	4	Normal	
12.	4	4	4	0	4				4	Normal	
13.	4	4	4	0		3			3	Normal	
14.	5	4	0	0	5	3		3	3	Medium valgoplanus	Too much evertor power was left in place.

of the peronaeus longus muscle is freed and is cut at the point of its insertion at the sole of the foot. This portion should be as long as possible. It is then pulled out at the first incision. A space between the triceps surae and the deep layer of leg muscles is opened by blunt dissection, thus preparing a wide and comfortable tunnel back of the fibula, directed above and behind the medial malleolus. A small incision is made at this point and the tendon is drawn through the tunnel, emerging at the point where the tibialis posterior tendon enters its tendon sheath. A fourth incision, four to five centimeters long, is made at the medial aspect of the mid-foot, centered below the tubercle of the navicular. The proximal border of the abductor hallucis is dissected and pushed downward; the tuberosity of the navicular and the end of the tibialis posterior tendon are dissected. The tendon sheath of the tibialis posterior is opened above the medial malleolus, and a curved probe is introduced into it, emerging with the tibialis posterior tendon at the sole of the foot. By means of the probe, the peronaeus longus tendon is pulled through the sheath of the paralyzed tibialis posterior tendon, which is wide enough to contain this second tendon.

TABLE IV

RECONSTRUCTION OF TIBIALIS POSTERIOR BY TRANSFER OF FLEXOR DIGITORUM LONGUS OR FLEXOR HALLUCIS LONGUS

	Preoperative Grading				Postoperative Grading					
Cases	Ext. Dig. Long.	Peron.	Tib. Ant.	Tib. Post.	Ext. Dig. Long.	Peron.	Tib. Ant.	Tib. Post.	Result	Remarks
15.	4	4	0	0		4	4	3	Normal	Combined with tibialis anterior reconstructed by extensor digitorum longus.
16.	3	0	0	0	3	0	0	3	Normal	
17.	4	5	3	0		5	3	4	Normal	Combined with reconstruction of triceps surae by extensor digitorum longus.

A narrow opening is drilled through the navicular on its plantar surface, proceeding laterally from the tubercle to the dorsum of the foot. The tendon is pulled through this bone tunnel and is anchored to the skin at the dorsum of the foot by a temporary Bunnell wire suture (Fig. 1). For further security, the transferred peronaeus longus tendon and the paralyzed tibialis posterior tendon are sutured together close to the insertion of the tibialis posterior tendon at the drill hole. The wounds are closed and the patient's leg is immobilized in a slightly equinovarus position in plaster for six weeks. Walking is permitted ten days after the operation, a heel being added to the plaster. Postoperative treatment consists in night-time splinting and muscle re-education. Variations of this method consist in substituting other muscles for the peronaeus longus as transfer.

When the flexor digitorum longus is used for transfer, only the last two incisions previously described are necessary and the incision above the medial malleolus is longer, about seven centimeters. The three deep muscles are freed and inspected. If the color of the flexor digitorum longus is found to correspond with the preoperative grading, the incision at the medial side of the mid-foot is made as described. By dissecting the short plantar muscles and drawing them away from the bones of the hind part of the foot, the flexor tendon is freed near its emergence from the retromalleolar tendon sheath. The flexor tendon is dissected distally as far as possible and is cut. It is then withdrawn at the first incision, reinserted through the tibialis posterior tendon sheath, and sutured to the navicular, as in the procedure described (Fig. 2).

The flexor hallucis longus muscle may be used for transfer in the same manner as the flexor digitorum longus.

The extensor hallucis longus muscle is also well suited for transfer. Its tendon is cut near the metatarsophalangeal joint. The distal end may be sutured to the long extensor tendon of the second toe. The proximal end is withdrawn at the anterior plane of the lower portion of the leg. As in Peabody's operation, the interosseous membrane is opened broadly. The retromalleolar incision, previously described, is made, the tendon is drawn through the interosseous space by means of a broad probe and is brought to the insertion of the paralyzed tibialis posterior tendon in the retromalleolar tendon sheath. The operation proceeds thereafter as has been described.

RESULTS

Twenty muscle-transfer operations have been performed for the repair of evertor-invertor muscle imbalance in valgus deformities of the ankle by replacement of the tibialis

TABLE V

RECONSTRUCTION OF TIBIALIS POSTERIOR BY TRANSFER OF EXTENSOR HALLUCIS LONGUS

	Preoperative Grading				Postoperative Grading					
Cases	Ext. Dig. Long.	Peron.	Tib. Ant.	Tib. Post.	Ext. Dig. Long.	Peron.	Tib. Ant.	Tib. Post.	Result	Remarks
18.	5	0	4	0	5	0	4	3	Normal	
19.	3	3	4	0	3	3	4	3	Normal	
20.	4	2	5	0	4	2	0	0	Severe valgo-planus	Combined with successful triceps surae reconstruction. Failure of anchorage; corrected later by Grice operation.

posterior muscle. The peronaeus longus muscle was used as motor power to substitute for the paralyzed tibialis posterior in fourteen patients (Table III), the flexor hallucis or flexor digitorum longus was used in three patients (Table IV), and the extensor hallucis longus was used in three patients (Table V). In six of these patients, a paralyzed or weak triceps surae muscle was reconstructed at the same time that the transfer was done.

In fifteen of these operations normal alignment of the foot was achieved. Valgus deformity was completely corrected and a firm longitudinal arch of the tarsal bones was produced.

Moderate valgus deformity resulted in three patients. In these patients the original deformity was much improved, but the new muscle did not have sufficient power to correct the valgus deformity entirely. The cause of the insufficient correction of muscle imbalance in these patients was miscalculation, either in the evaluation of the motor power of the muscle chosen for transfer or in the evaluation of the amount of motor power in the muscles responsible for the muscle imbalance.

In one patient, overcorrection resulted. Although in the early stages of this investigation we thought that overcorrection of dynamic valgus deformity was almost impossible, we learned that overcorrection can result as easily as undercorrection. At the beginning of our experiments, we tried to transplant both peroneal muscles to replace a paralyzed tibialis posterior. Varus deformities resulted in varying degrees of severity. This technique was abandoned, and the patients in whom the results were classed as failures due to faulty preoperative planning were not included in this report.

In one patient the anchorage of the transferred tendon was lost, resulting in failure of the operation. This patient was later operated upon a second time and the deformity was corrected by the second intervention.

The follow-up period of the patients shown in the tables was two to two and a half years. Transfers, once successful, tended to improve in motor power during the six months following removal of the plaster immobilization. The good results were permanent and these young patients will not need stabilizing procedures as they grow older.

Thirty-five similar operations were performed later which gave similar results. They are not included in this report since the follow-up period of these is considered too short to be conclusive.

SUMMARY

Dynamic valgus deformity in small children, three to eight years old, is caused by poliomyelitis which paralyzes the invertor muscles, the evertor muscles remaining normal.

This deformity cannot be corrected by apparatus. The procedure of tendon transfer, after careful evaluation of each patient, offers a solution to the problem of progressive deformity.

The transfer of tendons to substitute for paralyzed tibialis anterior muscles produced good results only in patients whose tibialis posterior muscles were normal. In most of these deformities the tibialis posterior was paralyzed, either singly or with paralysis of the tibialis anterior as well. Correction of the deformity was obtained by the substitution for the paralyzed tibialis posterior of a healthy muscle.

Replacement of this important muscle was achieved largely through use of the peronaeus longus or the flexor digitorum longus. Other muscles may also be used for this purpose, the flexor hallucis longus and the extensor hallucis longus being well suited for this transfer.

Twenty patients who have undergone this operation have been followed for two to two and one-half years. In fifteen of these patients, normal foot alignment resulted, and in three cases the deformity was improved. One overcorrection and one failure resulted. In six of the patients reconstruction of the tibialis posterior was combined with a tendon transfer for paralysis of the triceps surae.

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Intervertebral-Disc Degeneration Considered as a Pressure Atrophy

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Intervertebral-disc degeneration has been commonly looked upon as part of the aging process, and there has been less interest in changes of the annulus fibrosus than in the involution of the nucleus pulposus, its loss of water [14, 22], its cellular degeneration [5], and its escape into bone or annulus fissures [14, 25, 28].

The fact that disc degeneration and rupture may occur long before adult age indicates that the normal process of aging—the ordinary wear and tear of the disc tissues—is only partly responsible. Therefore, some other destructive agent must be present. It has been demonstrated that one such agent is trauma [3, 11, 14, 25]. Williams identified another when he pointed out that the heavy weight on the posterior portion of the annulus fibrosus of the lumbosacral disc causes eventual disc rupture.

The purpose of this paper is to correlate certain findings which point in the same direction: disc degeneration considered as a pressure atrophy or pressure considered as an agent in disc degeneration and rupture.

EXPERIMENTAL STUDIES OF INTERVERTEBRAL-DISC COMPRESSION IN RATS' TAILS

In order to study the effect of increased pressure on intervertebral discs, rats' tails were tied up and fixed in the shape of a U. It was found that degeneration and even rupture occurred on the concave side of the tails while the convex side remained normal *. A preliminary report of this experiment was published in 1952 [20]. In the present study the results of the earlier experiments are included as well as results of the later ones.

Material

The tails were treated as follows: sixteen tails were tied up for 75, 90, 140, 158, 176, 225, 250, 278, 320, 390, and 420 days; five tails were tied up for 76 days, then released for 180 days; three tails were tied up for 425 days, then freed for 22, 120, and 225 days; and nine tails were tied up for twelve hours and freed for twelve hours, alternately, for 75, 138, 230, 280, and 330 days.

Longitudinal sections were made of two or three discs from the curved portions of the tails, and, in most of the animals, from one or two discs from the straight portions of the tails. Paraffin embedment was used; in a few instances celloidine embedment was added.

Results

Microscopic examination of the tails revealed in every instance a changed structure of the annulus fibrosus on the concave side, while the structure of the annulus fibrosus on the convex side did not differ from that seen in straight portions of the tails (Figs. 1 through 3-D). On the concave side the destruction consisted of curved, swollen, and broken connective-tissue bundles with a decrease in the number of cells (Figs. 4 through 7). The degree of change varied, the variation depending upon the length of the period of fixation and the degree of curvature. Tails in the twelve-hour fixation group showed less pronounced changes than those with longer fixations. Longstanding fixation was followed

* No injury occurred except that in three intervertebral discs the annulus fibrosus loosened from its attachment to the bone. It was replaced by callus. These discs were not included in the series.

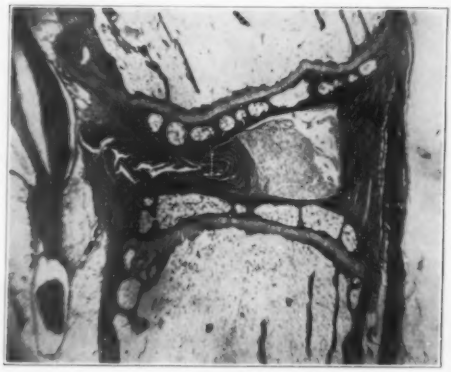

FIG. 1

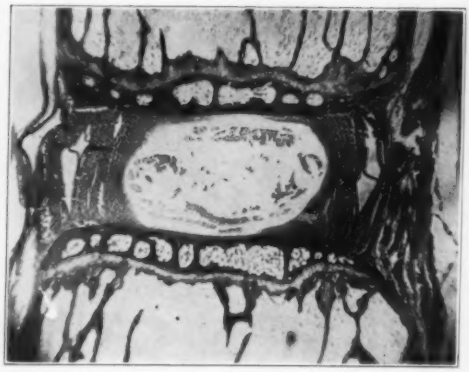

FIG. 2

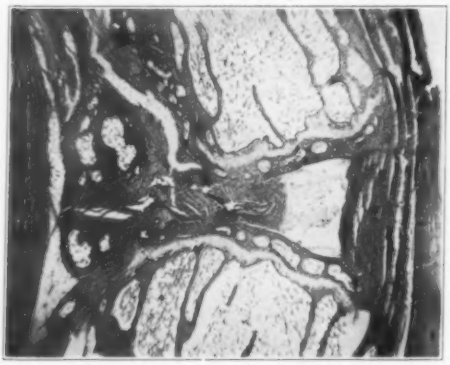

FIG. 3-A

Fig. 1: Microscopic section of an intervertebral disc from the curved portion of a rat's tail which had been tied up in a U shape for 320 days. There is degeneration and rupture on the concave side with moderate proliferation of connective tissue at the rupture.

Fig. 2: Normal disc from a straight portion of the tail shown in Fig. 1.

Fig. 3-A: Disc from the curved portion of a tail which had been tied up for 390 days. There is heavy reaction outside the disc rupture with formation of connective tissue and bone.

by proliferation of connective tissue and even bone formation, as well as by bulging and rupture of the disc in some degree on the concave side (Figs. 1 and 3-A). Areas of granulation tissue were present in the region adjacent to the ruptured disc.

In the nucleus pulposus there was a tendency to increased vacuolization of the cells in the curved portions of the rats' tails (Figs. 9 and 10). Almost total destruction of the cells was found in three discs (Fig. 8).

Conclusions

Degeneration and rupture of the annulus fibrosus occur as a result of pressure for a long period of time on the concave side of a curvature of a rat's tail. The nucleus pulposus may also be influenced by the curvature, although it will be less pronounced. Outside the degenerated and ruptured annulus fibrosus, a proliferative process may take place similar to that which is seen in herniated intervertebral discs in man.

ANATOMICAL STUDIES OF THE LOCATION OF INTERVERTEBRAL-DISC RUPTURES IN RELATION TO SPINAL CURVATURES

According to several authors [9, 12, 24], the radial fissures are most often found dorsally in the lower lumbar region. In anatomical studies by Haglund in 1942 and by Lindblom in 1941 and 1944, the cervical and lower lumbar intervertebral discs were found to be ruptured far more often in a posterior or posterolateral direction than in an anterior or lateral one. In order to determine the direction of disc ruptures in the thoracic region, a corresponding study of thoracic intervertebral discs was made.

Material

Twenty anatomical specimens of thoracic spines, most of them decalcified, were

FIG. 3-B

Figs. 3-B, 3-C, and 3-D: Details of ruptured annulus fibrosus and osteophytes in the tail shown in Fig. 3-A.

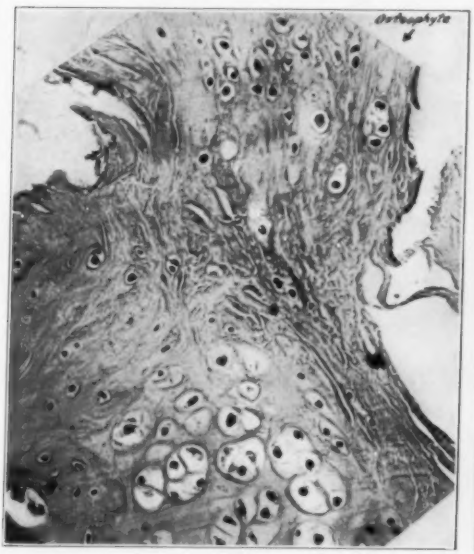

FIG. 3-C

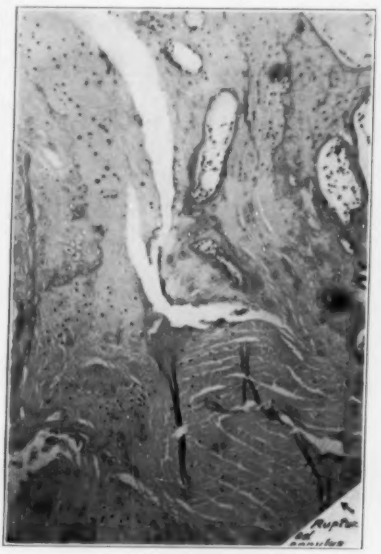

FIG. 3-D

dissected. In order to find radial ruptures, the discs were cut horizontally into thin slices. This was the same technique which was used in the study of cervical and lumbar intervertebral discs. The injection of red lead into the disc spaces, as was done in the cervical and lumbar disc studies, was not successful in the thoracic disc spaces.

Results

Radial ruptures from the disc centers were found as commonly in thoracic discs as in cervical and lumbar discs. There were eighty-one distinct radial ruptures in the thoracic intervertebral discs; 57 per cent of these ruptures were dorsal or dorsolateral in direction, and 43 per cent were frontal or lateral. In comparison, 87 per cent of the ruptures in the

FIG. 4

Fig. 4: Detail of a compressed disc from the concave side of a tail tied up for twelve hours daily for 280 days. There is degeneration of the annulus fibrosus with swollen and acellular connective-tissue bundles; rupture with necrotic fragments is seen close to the bone.

Figs. 5, 6, and 7: Details of annulus fibrosus from a tail tied up for 76 days and free for 180 days. In Fig. 5, swollen and acellular bundles are seen at a rupture site on the concave side, and in Fig. 6, acellular bundles in a pre-rupturing stage appear near the nucleus pulposus. Fig. 7 shows normal tissue bundles and cells on the convex side of the same disc.

Fig. 8: Detail of degenerated nucleus pulposus of the disc shown in Figs. 5 to 7.

Figs. 9 and 10: Details of two nuclei pulposi from a tail tied up for twelve hours daily for 138 days. In Fig. 9, nucleus from the curved portion shows moderate degeneration. Fig. 10 shows nucleus from the straight portion of a tail. The cells appear normal.

FIG. 5

FIG. 6

FIG. 7

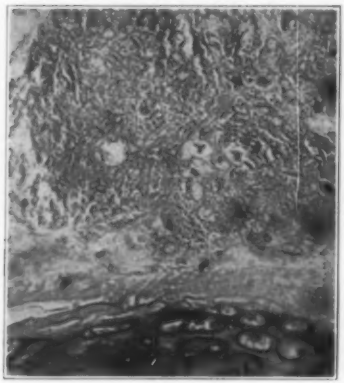

FIG. 8

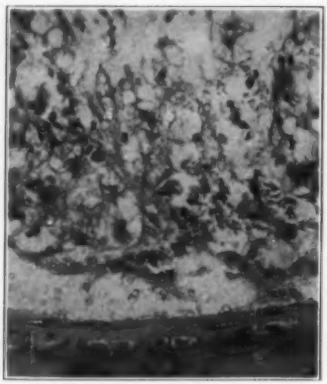

FIG. 9

FIG. 10

lumbar region were dorsal or dorsolateral in direction, and 13 per cent were frontal or lateral (Fig. 11).

Fourteen thoracic discs showed isolated degeneration foci with definite cavities in the anterior portion of the annulus fibrosus. A similar finding in the lumbar region was exceptional. The anterolateral direction was found most frequently in peripheral and radial intervertebral-disc ruptures of the thoracic region, despite the fact that the posterior portion of the annulus fibrosus is much thinner in the thoracic region than it is in the lumbar region.

Conclusion

Radial ruptures which represent the early phase of intervertebral-disc rupture have a tendency to occur on the concave side of spinal curvatures.

ROENTGENOGRAPHIC STUDIES OF THE EFFECT OF SHOE HEELS ON THE STATICS OF THE LUMBOSACRAL SPINE

The object of these studies was to determine the effect on the lumbar spine of a support similar to shoe heels.

Material

Thirty adult patients, examined roentgenographically for a variety of diseases, were chosen as subjects for roentgenograms for our study. Two lateral roentgenograms were made of each subject, one without shoes, the other with a support of six centimeters placed under the heels.

Drawings were made from these roentgenograms, showing the positions of the anterior surfaces of the sacrum and the lumbar vertebrae. The promontory of the sacrum was chosen as the point of zero for our calculations.

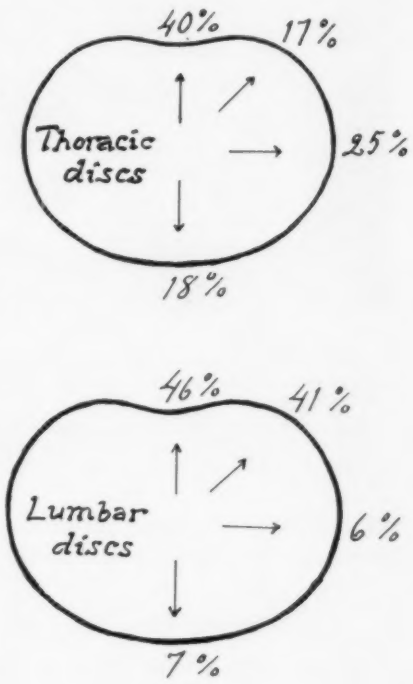

FIG. 11

Diagrams showing the frequency of occurrence of radial disc ruptures in thoracic and lumbar intervertebral discs. The basic material for the study consisted of 220 thoracic intervertebral discs having eighty-one radial ruptures, and 960 lumbar intervertebral discs having 393 radial ruptures.

Results

The results of the study were put together in a diagram (Chart I). In twenty-three subjects, the heel support caused a reduction of 2 to 11 degrees in the angle between the sacrum and the fifth lumbar vertebra. In six subjects the angle was unchanged and in one it was increased. Roentgenograms of most of the subjects showed a posterior displacement of the lumbar spine with a tendency to compensate by anterior deviation and by an increase of kyphosis at the transition between the lumbar and the thoracic portions of the spine. Anterior tilting of the pelvis was seen in ten subjects. Increased lordosis and tilting of the pelvis caused by heel support are shown in Figures 12-A and 12-B.

Conclusions

Elevation of the heels by a support is followed by compensatory changes in the equilibrium of the spine. The forced angulation in the lumbosacral region produces an increased pressure on the posterior portion of the lower lumbar intervertebral disc. The

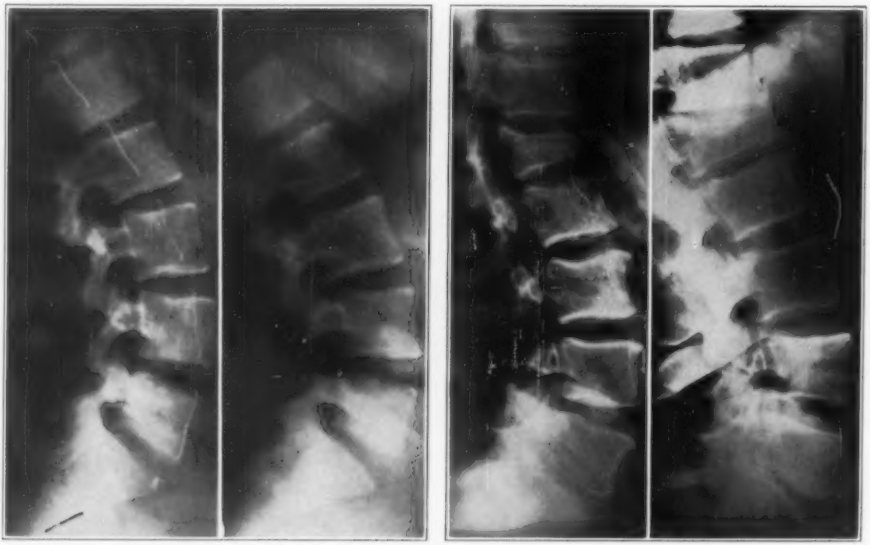

FIG. 12-A FIG. 12-B FIG. 13-A FIG. 13-B

Figs. 12-A and 12-B: Lateral roentgenograms of a standing person (*A*) without and (*B*) with support under the heels. The anterior vertebral outlines on *B* are marked on *A*. Note the increased lordosis of the lumbar spine.

Figs. 13-A and 13-B: Lateral roentgenograms of a patient with a fracture of the first lumbar vertebra; *A*, a recent fracture; *B*, nine years later. Anterior vertebral outlines in *B* are marked on *A*. Note the posterior displacement of the lumbar spine and the narrowing of the lumbosacral intervertebral disc.

heel support used in these experiments was high in order to demonstrate clearly the principles of its effect on the statics of the lumbosacral spine.

MYELOGRAPHIC STUDIES OF THE LOCATION OF LUMBAR INTERVERTEBRAL-DISC HERNIATION IN MEN AND WOMEN, AND IN RELATION TO LUMBAR SCOLIOSIS

The purpose of this study was to determine if there is a difference in the location of intervertebral-disc herniation in men and women with low-back and sciatic pain, and if there is a difference between the two sides in lumbar scoliosis.

Material

The material consisted of two series of patients. The first series were patients with actual low-back and sciatic pain who had been examined with myelography by abrodil [1, 17]. There were 449 patients in this series; 328 disc herniations were visualized with operative verification. For the second series, fifty-one patients with a history of lumbar scoliosis and sciatic pain were selected from subjects in a field examination of 1,200 workers [13].

Results

Of the 449 patients in whom myelography was done, 234 had distinct intervertebral-disc herniations with flattening of the passing nerve roots in the lateral portion of the spinal canal. In 128 (55 per cent) of these patients, the herniation was on the left side; and in 106 patients (45 per cent) the herniation was on the right. In ninety-four patients a mid-line herniation was present. Frequency of herniation of the fourth to fifth lumbar intervertebral disc was 10 per cent higher in men than in women (standard error ± 5.5). Herniation of the lumbosacral intervertebral disc was 12 per cent higher in women than in men (standard error ± 5.5) (Chart II).

Definite scoliosis was present in 107 of the 234 patients having distinct disc herniation and nerve-root compression laterally in the spinal canal. Chart III shows the location of the herniation in relation to the concavity of the curvature in scoliosis. It must be remembered that in lumbar scoliosis there are usually two concavities, the upper one at the second to fifth lumbar vertebral level and the lower one at the lumbosacral disc (Chart III). Most of the disc herniations in this series were situated on the concavity of the curvature.

Lumbar scoliosis, visualized roentgenographically, was found in 292 of 709 patients (41 per cent) examined in the orthopaedic section of the field examination of 1,200 workers. We consider this to represent a normal occurrence of scoliosis in the lumbar spine. The frequency of scoliosis found in the patients in whom myelography was done was 47 per cent. The average age of the patients was about the same in the two series. The difference in occurrence of scoliosis between the two groups is too small to make one believe that so-called sciatic scoliosis is responsible for the tendency of disc herniations to locate on the concavity of the curvature.

TABLE I

THE DIRECTION OF SCOLIOSIS AND THE OCCURRENCE OF INCREASED DORSAL KYPHOSIS

Age	* ThSin (*Per cent*)	ThDx (*Per cent*)	LSin (*Per cent*)	LDx (*Per cent*)	Ky (*Per cent*)
25 to 39 years (435 patients)	13	32	22	13	16
40 to 55 years (275 patients)	17	42	25	19	25

* Th: thoracic scoliosis; L: lumbar scoliosis; Sin: convexity to the left; Dx: convexity to the right; Ky: increased dorsal kyphosis.

The fifty-one patients with a history of sciatic pain were dealt with in the following way: the roentgenologist estimated the probable position of the disc herniation from the site of the concavity of the curvature, and the clinician related this assumption to the patient's history of symptoms and to the presenting localised neurological signs. There was agreement between roentgenologist and clinician in thirty-six of the fifty-one cases, a statistical indication of the relationship between concavity of the curvature in scoliosis and the affected side in sciatica or disc herniation.

The number of errors may be understood if the anatomical conditions are considered in the following way:

In scoliosis, there are two curvatures in the lower lumbar region. One is the lordosis curve, the other is the curve of scoliosis. Usually the lordosis has the greater degree of curvature. As the disc prolapses before protruding, it often works its way to one or the other side of the superficial layers of the annulus fibrosus. There is a zone of expansion in the location of the prolapse. Without scoliosis, this zone is posterior; with scoliosis, the zone is still posterior but closer to the concavity of the scoliosis.

However, the agreement between roentgenologist and clinician represents a statistical indication of the relationship between concavity of the curvature in scoliosis and the affected side in sciatica or disc herniation.

Conclusions

The intervertebral-disc herniations causing low-back and sciatic pain are predominately situated on the concavity of the curvature.

The location of intervertebral-disc herniation is different in men and in women; the fifth lumbar intervertebral disc is more often affected in women than in men.

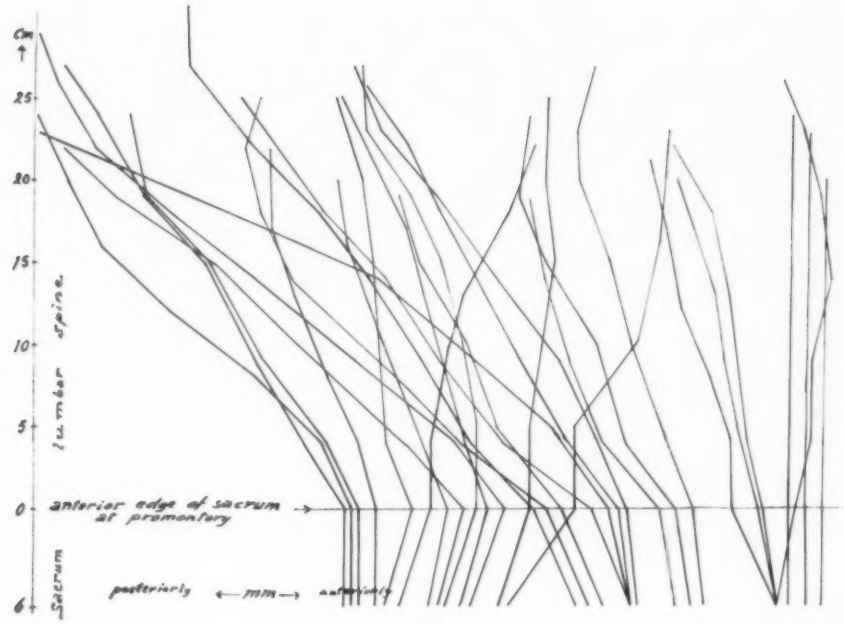

CHART I

Diagram showing the displacement of the lumbar spines and sacrums of thirty persons in standing position with a support six centimeters high placed under the heels. Each line represents one person. The straight vertical line indicates no displacement. Deviation to the left above the 0 line indicates posterior displacement of the anterior outlines of the lumbar vertebrae, and deviation to the right indicates anterior displacement. A changed direction of the sacrum is shown below the 0 line. Diagram was made from lateral roentgenograms of the subjects.

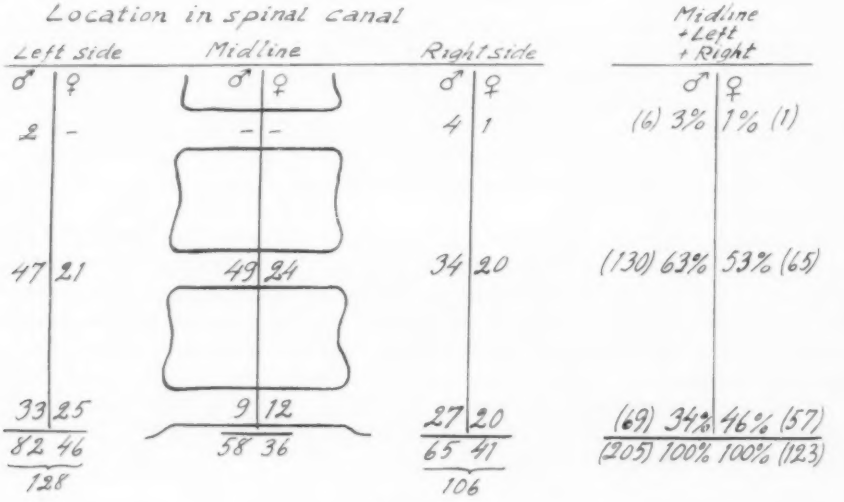

CHART II

Diagram of the location of lumbosacral disc herniations in the myelographic material. The difficulty of diagnosis of intervertebral-disc herniations at the lumbosacral junction is due to the inadequacy of the myelographic method at this point, because of the narrow dural sac and the short nerve-root sheaths. At the right is a table of the percentages of visualized herniations of the different herniated discs.

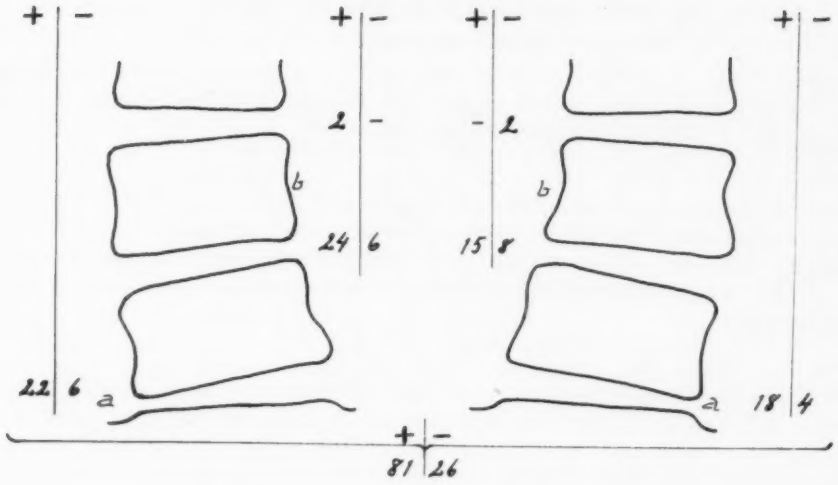

CHART III

Diagram of the location of intervertebral-disc herniations in scoliosis demonstrating the areas *a* and *b* of concavity where most disc herniations occur. + = homolateral to compression side of the disc; − = contralateral. Herniation at the left occurred in sixty patients with scoliosis and in sixty-eight patients without scoliosis. Herniation at the right occurred in forty-seven patients with scoliosis and in fifty-nine patients without scoliosis.

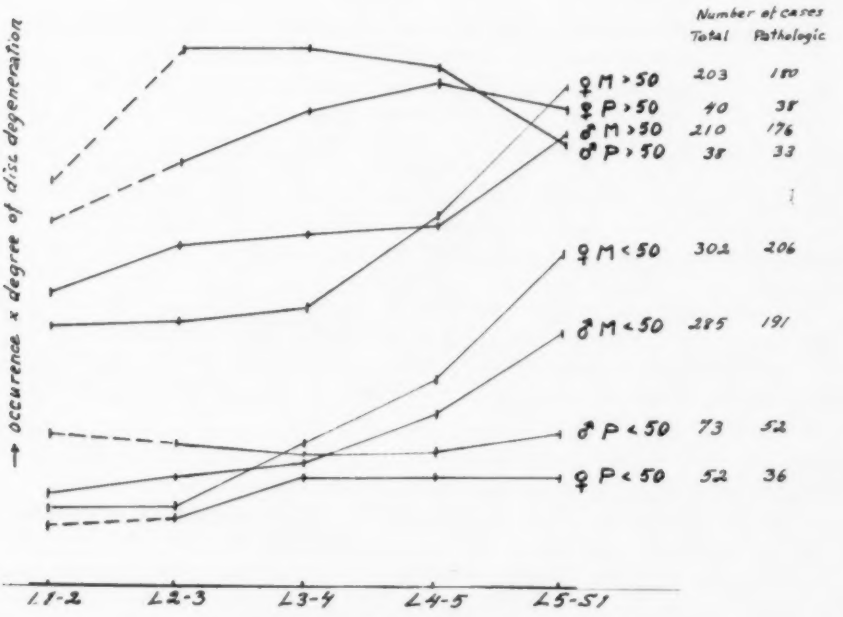

CHART IV

Diagram showing the occurrence of indirect signs of herniated intervertebral discs in primitive populations (*P*) and in modern populations (*M*). The modern series are grouped as *below* and *above* fifty years of age. The primitive series are grouped as *young* and *old*, but are marked < 50 and > 50, respectively. The dotted lines represent incomplete material in the regions indicated.

ROENTGENOGRAPHIC STUDY OF THE FREQUENCY AND DIRECTION OF SCOLIOSIS AND OF THE OCCURRENCE OF INCREASED DORSAL KYPHOSIS

The object of the study was to determine the normal frequency of lumbar scoliosis with convexity to the left and to the right. Since scoliosis as well as kyphosis increases with age, the age factor was considered in our study.

Material

The material for study consisted of roentgenograms of the spines of 709 men and women between the ages of twenty-five and fifty-five years. Their occupations were varied —some did light work and some, heavy work. The statistics concerning men were taken from the field study of Hult in 1954. His material was supplemented by a corresponding study of women.

Results

The direction of the scoliosis and the occurrence of increased dorsal kyphosis is shown in Table I. Under normal conditions, thoracic scoliosis with convexity of the curvature to the right and lumbar scoliosis with convexity of the curvature to the left predominate. These conditions, as well as pronounced kyphosis, increase in frequency with advancing age. The increase of deformity which is seen in older persons with kyphosis may be considered the evidence of progression from latent or slight deformity to definite deformity. No difference in the occurrence was found between men and women.

Conclusions

Convexity of the curvature to the left is found most frequently with lumbar scoliosis; this finding is in agreement with the fact that the location of intervertebral-disc herniations is related to the direction of the curvature of the scoliosis (Chart III).

STUDIES OF THE DISTRIBUTION OF SIGNS OF DEGENERATION OF INTERVERTEBRAL LUMBAR DISCS IN MODERN AND PRIMITIVE POPULATIONS

It is known that changes in spondylosis deformans are due to disc degeneration [4, 25].

In an earlier paper [19] the author stated that there is a definite difference between modern and primitive populations in the distribution of degeneration of lumbar intervertebral discs. Since then, there has been added to our study a series of the lumbar spines of prehistoric Swedes, as well as spines of a later Swedish people estimated to have lived about 1100 A.D. This material was found at an ancient church and has the added value of positive differentiation between the sexes, since apparently it was the custom to bury men at one side of a church and women at the other side.

In these two series of primitive material, the lumbar vertebrae and the sacrums were carefully assembled for study. Occurrence of osteophytes with and without narrowing of the intervertebral spaces was noted. The study material of the modern population was a series of roentgenograms of lumbar spines, by means of which the presence of osteophytes and lowered discs was determined.

Material

The material consisted of four groups:

1. Spinal roentgenograms of 1,000 modern Swedish men and 1,000 modern Swedish women who had been examined principally because of back trouble;

2. The series described earlier, consisting of 572 men chosen from a field examination of normally healthy people, and a supplementary group of 137 women—a total of 709 subjects;

3. Two hundred and three lumbar spines of a primitive Swedish people (fifty-nine were positively men, and fifty-seven were probably men; forty-four were positively women and forty-three were probably women *);

* Courtesy of Mr. N. G. Gejvall, Statens Historiska Museum, Stockholm.

4. Two hundred and ninety lumbar spines of prehistoric American Indians and Eskimos **.

Results

Disc degeneration in the different groups of material studied was recorded as a graph (Chart IV). As the curves of Group 1 and Group 2 did not differ, the results of Group 2 were not recorded. In Group 3, the curves for "positively" and "probably" were almost identical; therefore they were thrown together. The course of the curves of Group 4 was similar to that of Group 3. Since the curves of Group 4 were shown in an earlier paper [19], they are not included here. Modern American Indian and Eskimo material has not been available for a comparative study, which makes the prehistoric Indian and Eskimo material of doubtful significance.

It is seen in Chart IV that in modern populations the lower lumbar intervertebral discs are more often affected than the upper ones, and that the lumbosacral intervertebral disc is more often affected in women than in men. In the primitive populations, disc degeneration appeared to be more equally distributed in the spinal region in both men and women. It is also shown that this distribution is independent of age.

It is true that the spines of the modern and the primitive populations were studied by two different methods. However, the method of investigation has no bearing on the existence of sex differences in the location of lumbar-disc degeneration in the modern material and the absence of these differences in the primitive material.

Conclusions

In a modern population, both men and women probably have a higher tendency to disc degeneration in the lower region of the spine than primitive people had. Modern women have a higher frequency of degeneration of the lumbosacral disc than modern men. This difference was absent in primitive men and women; therefore, the reason for it must lie in modern ways of living.

DISCUSSION

The deleterious effect on rats' tails resulting from long fixation in a curved position must be regarded as a pressure atrophy. The principle is the same as the strong tendency of human intervertebral discs to rupture on the concave side of curvatures, lordotic and scoliotic.

Since a support under the heels tends to increase the lordosis in the lower lumbar region, the wearing of high heels can be regarded as a parallel to the experiment of curvature of the rats' tails, causing compression of the posterior portion of the lower lumbar discs which is found more frequently in women than in men. This may explain both the differences in the location of herniated intervertebral discs in men and women and the more frequent occurrence of disc degeneration in the lower lumbar region in a modern population than in the same portion of the spine in a more primitive people.

Disturbances in the statics, leading to a compression of the posterior portion of the lower lumbar discs similar to that caused by shoe heels, may occur as the result of vertebral fracture. This is illustrated in Figures 13-A and 13-B. Vertebral fractures are not rare in childhood [23] and they cause a dorsal kyphosis which increases with age. Scheuermann's disease, whether post-traumatic or not, also results in a compensatory forced lordosis in the lumbar region. Finally, decreased turgor of the nucleus pulposus itself by intraosseous herniation or central fracture [8, 21] will eliminate the centrifugal or stretching forces on the annulus fibrosus so that the compression force on the disc will become pre-

** Courtesy of Mr. T. D. Stewart, Smithsonian Institute, Washington, D. C.

dominately longitudinal, compressing and injuring the annulus fibrosus in a way comparable to the injury of the discs in the rats' tails which were able to tolerate stretching but not compression.

SUMMARY

Disc degeneration is defined as a pressure atrophy; the premise is set forth that the use of shoe heels is a cause of pressure atrophy of the posterior portions of the lower lumbar intervertebral discs.

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Swivel for Proximal Radio-Ulnar Synostosis

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Disability resulting from union of the two bones of the forearm distal to the insertion of the pronator teres can be ameliorated by the use of several procedures, either singly or in combination. These procedures include resection of the bone bridge and interposition of tantalum foil; derotation osteotomy of the radius and ulna in order to bring the hand into a position of mid-supination; resection of a segment of the ulna at the level of the synostosis combined with fusion of the wrist in a favorable position; and derotation osteotomy of the radius with resection of the distal inch of the ulna.

In proximal radio-ulnar synostosis the problem is more complicated; in fact, so far as we know, no method has yet been devised which will ensure that, following separation of the radius from the ulna, the hand can be brought into pronation and supination by action of the radius.

Proximal radio-ulnar synostosis usually occurs near the area in which the muscular branches of the radial nerve penetrate the supinator muscle; thus, in attempting to remove the bone bridge, the surgeon runs the risk of damaging this nerve. Another problem in the treatment of this condition is that even after seemingly adequate clearance of the

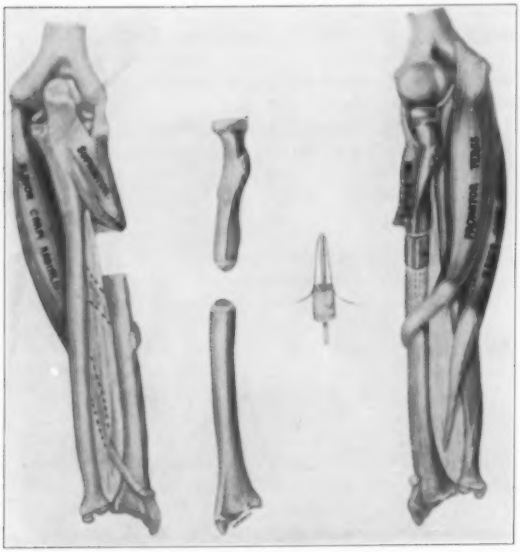

FIG. 1-A

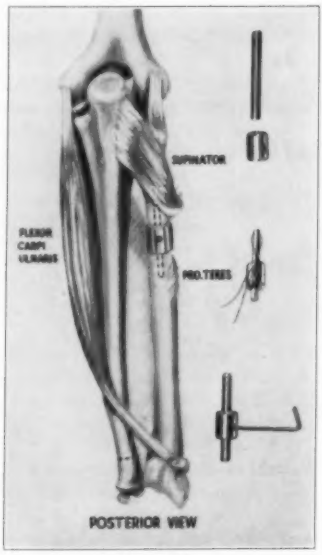

FIG. 1-B

Fig. 1-A: Drawing showing the insertion of a swivel in a forearm in which the flexor carpi radialis has been transplanted to serve as the supinator.

Fig. 1-B: Drawing of a forearm in which the more effective flexor carpi ulnaris has been transplanted to serve as the supinator. The dotted line across the distal end of the ulna shows the level at which the resection will be done.

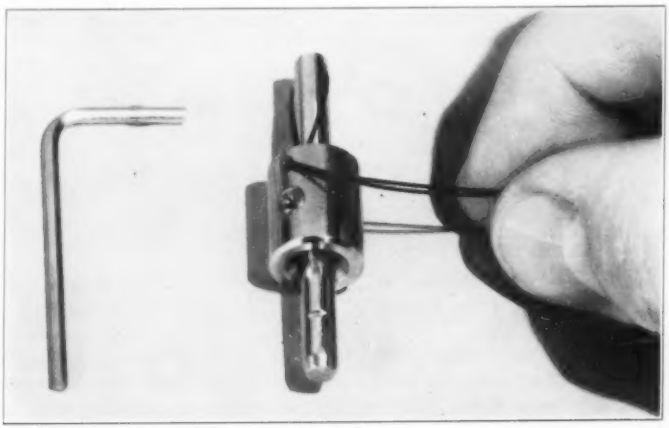

FIG. 1-C

Photograph of the prosthesis after the central rod has been pulled down into the appropriate position.

space between the two bones near the elbow, synostosis will recur unless a sizable segment of the proximal end of the radius is also removed. Resection of the radius involves complications. As a result of removal of the head and an inch or two of the adjacent portion of the shaft, the action of the supinator is nullified. Even more serious—in fact, possibly calamitous in consequence—resection of too large a segment will leave the end of the remaining bone without support or anchorage, with the result that (1) the unsupported proximal end of the radius will incline toward and impinge upon the ulna, making pronation and supination painful, if not impossible; and (2) the power of the wrist will be weakened (for the radius is the main supporting bone of that joint), which means that the

wrist, in turn, cannot provide a firm, stable counterabutment for the carpal bones. A final consideration is that, when the radius is shortened, due either to resection of the proximal portion or to ulnar deviation of the remaining portion of the shaft or to both, the ulna becomes comparatively longer and its distal articular end pushes down toward the carpus, making pronation and supination painful.

In the procedure illustrated in Figures 1-A, 1-B, and 1-C, we feel that some of these hazards have been eliminated. This procedure has been successfully used in four cases of synostosis of traumatic origin. Two of these cases are presented here (Figs. 2-A through 3-H). In all four cases the entire procedure was carried out at one surgical session, but for purposes of clarity the various steps will be described in separate sections.

INSERTION OF THE SWIVEL

The proximal end of the radius is approached through a longitudinal incision which is begun at a point just distal to the lateral portion of the cubital crease. The deep fascia of the forearm is incised and the belly of the brachioradialis is retracted radially, exposing the radial artery and the cutaneous branch of the radial nerve, which lies lateral to the artery. The tendinous insertion of the pronator teres which curls around the junction of the upper and middle thirds of the radius is identified, and the fibers of the supinator attached to the radius just proximal to this insertion are removed, following which an inch of bone is resected.

The swivel is made of stainless steel, and consists of a cylinder-shaped body and a central rod. The cylinder should be slightly shorter than the piece of bone resected and of about the same size in girth; there are depressions in the upper and lower surfaces, and there is a set-screw at the mid-section. The cylinder is perforated from top to bottom in order that the central rod may be inserted; the perforation is large enough so that the rod may glide easily. The central rod is three times the length of the cylinder and one-third of its size in diameter. There is a small hole beneath the superior rim of the cylinder and one through the upper portion of the central rod. A loop of suture wire is placed through these holes, and when this loop is tugged, the central rod glides down within the cylinder to the desired level, where it can be secured by tightening the set-screw.

The medullary cavity of the proximal fragment of the radius is reamed and gouged in order that two inches of the central rod of the prosthesis may be inserted; the cavity of the distal fragment of the radius is similarly widened as far as about an inch from the resected end. Because of the synostosis, the proximal fragment of the radius is fixed; it cannot be moved or levered. The central rod of the swivel is inserted into the cylinder until its distal end is flush with the lower rim; the extruding two inches of the rod is then inserted into the end of the proximal fragment. The cylinder is now aligned with the proximal end of the distal fragment, and by pulling the wire, previously threaded through the holes in the upper rim of the cylinder and the proximal end of the central rod, an inch of the central rod is doweled into the distal fragment. The position of the central rod within the medullary cavities of the two radial fragments is ascertained by roentgenographic study; each fragment should contain about one inch of the rod. When the rod is in this position, it is secured by tightening the set-screw with an Allen wrench.

RESTORATION OF SUPINATOR FUNCTION

In proximal radio-ulnar synostosis the action of the supinator muscle is nullified. In order to counterbalance the pronator teres and to bring the hand into supination, either the flexor carpi radialis or flexor carpi ulnaris may be used, the insertion of one of these muscles being shifted to the distal fragment of the radius. In transfer of the flexor carpi ulnaris the dissected distal portion of the muscle is brought obliquely over the dorsum of distal end of the forearm bones and is anchored into the bulbous end of the radius about an inch and a half above the styloid process. This muscle makes a more effective supina-

FIG. 2-A

FIG. 2-B

Figs. 2-A through 2-E: Case 1. A typical case in which the proximal fragment of the radius was sufficiently long to receive the proximal portion of the central rod of the prosthesis.
Fig. 2-A: Roentgenogram of the forearm showing proximal radio-ulnar synostosis.
Fig. 2-B: Roentgenogram showing the forearm following insertion of the swivel.

FIG. 2-C

FIG. 2-D

Photographs showing the postoperative range of pronation (45 degrees) and supination (30 degrees).

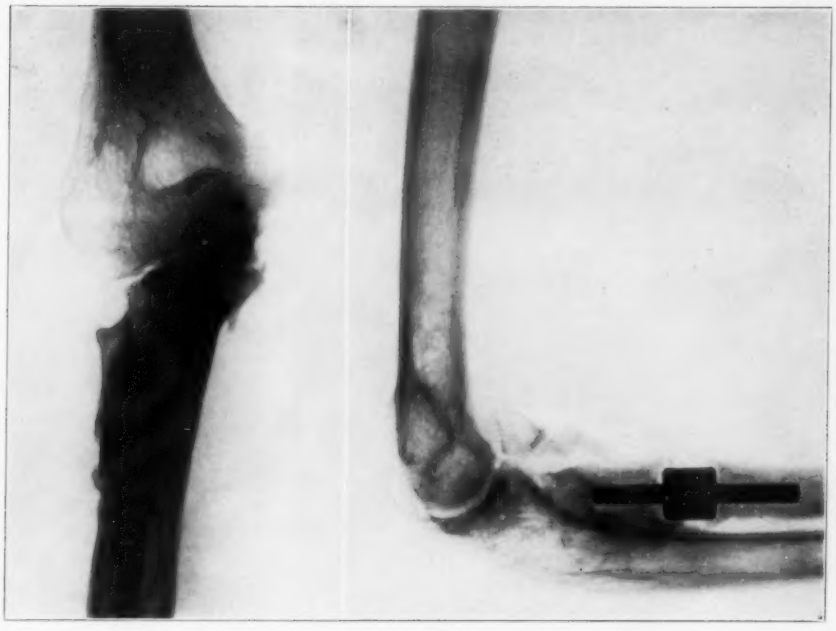

FIG. 2-E

Roentgenograms, made September 1946, showing the satisfactory end result.

tor than the radialis muscle, but some women object to the bulky prominence that it produces over the dorsum of the distal end of the forearm; therefore, in one of our cases the more tendinous flexor carpi radialis was utilized. In transfer of this muscle, the tendon was brought through a hole in the interosseous membrane, over the distal end of the radius, and moored into the radial border of the membrane just under the insertion of the brachioradialis. The resulting range of supination was not as great as that obtained when the flexor carpi ulnaris was used.

RESECTION OF THE DISTAL END OF THE ULNA

In practically all patients with proximal radio-ulnar synostosis due to trauma, the radius is shortened, which—relatively—increases the length of the ulna. In these patients the distal end of the ulna impinges on the articular disc and, through it, on the triangular bone, with the result that pronation and supination cannot be painlessly carried out unless the distal inch of the ulna is resected. Resection of the distal end of the ulna may be accomplished through the incision used for the dissection of the flexor carpi ulnaris; or, if the flexor carpi radialis is transplanted, the resection may be accomplished through a small incision made along the ulnar border of the distal end of the forearm.

Postoperatively the arm is encased in a cast immobilizing both the elbow and wrist with the forearm in a position mid-way between pronation and supination. The cast is removed after six weeks, at which time the attachment of the transplanted tendon to the distal end of the radius should be firm. Functional exercises are then initiated.

CASE HISTORIES

CASE 1. Mr. H., twenty-eight years old, a foreman in a factory, had injured his right elbow in 1950. This injury had consisted in dislocation of the elbow with fracture of the coronoid process of the ulna and comminution of the head of the radius. Open reduction of the dislocation and removal of the broken frag-

FIG. 3-A

FIG. 3-B

FIG. 3-C

FIG. 3-D

FIG. 3-E

Figs. 3-A through 3-H: Case 2. In this case the proximal radial fragment was not sufficiently long to hold the proximal portion of the central rod of the prosthesis.

Fig. 3-A: Lateral roentgenogram of the elbow made immediately after the original injury.

Fig. 3-B: Lateral roentgenogram made in November 1955, just before insertion of the swivel.

Fig. 3-C: Anteroposterior roentgenogram made in November 1955, just before insertion of the swivel.

Figs. 3-D and 3-E: Roentgenograms made following the insertion of the swivel, showing the forearm in supination and pronation.

FIG. 3-F

FIG. 3-G

Photographs made eight months after the surgery, showing the range of pronation (25 degrees) and the range of supination (60 degrees).

ments of the head of the radius had been done elsewhere. Subsequently there had developed proximal synostosis between the radius and ulna of the right forearm.

In 1951, a year after the initial treatment, the patient came to us; at this time his forearm was fixed in a position of extreme pronation, which made his hand useless (Fig. 2-A). The swivel was inserted (Fig. 2-B). Five years later, in 1956, the over-all result was fairly satisfactory and the functional result was excellent. The range of pronation from the mid-position was 45 degrees (Fig. 2-C), while the range of supination was 30 degrees (Fig. 2-D), making a total range of 75 degrees. The patient had no discomfort, and roentgenographic study (Fig. 2-E) showed that the swivel was in excellent position. Roentgenographic study also showed that the synostosis was still present between the proximal portions of the radius and ulna.

CASE 2. In January 1954, Mrs. F., a housewife aged sixty-three, had fallen down some steps and sustained a fracture-dislocation of the right elbow (Fig. 3-A). Closed reduction had been performed by her family physician, but the result had been non-union of the ulna and complete inability to pronate and supinate the forearm. In September 1954, another surgeon had treated the ulnar fracture by the insertion of an intramedullary rod and application of a plate. In January 1955, a year after the injury, the plate had been removed and two screws substituted; at the same time, the proximal end of the radius had been resected, the removed bone being applied as a graft across the still ununited fracture of the ulna. Following this treatment, the ulnar fracture had at last united.

In November 1955, the patient came to us with complete inability to pronate and supinate the forearm and with pain over the distal radio-ulnar joint (Figs. 3-B and 3-C). The rod and the screws were removed from the ulna, and a swivel was inserted (Figs. 3-D and 3-E). Since the remaining portion of the proximal

FIG. 3-H

Fig. 3-H: Follow-up roentgenograms made in October 1956.

radial fragment was not sufficiently long to hold the proximal end of the rod, this end of the rod was inserted through the radial fragment into the proximal portion of the ulna. The distal inch of the ulna was resected. The circular defect in the distal end of the radius which appears in Figure 3-E is the drill hole into which the tendon of the flexor carpi ulnaris was moored. Eight months after surgery, the range of pronation was 25 degrees (Fig. 3-F), and the range of supination was 60 degrees (Fig. 3-G). The end result almost one year after surgery is shown in Figure 3-H.

SUMMARY AND CONCLUSIONS

A method of treatment for proximal radio-ulnar synostosis has been described. This method has been used in four patients in whom the condition was of traumatic origin. Two case histories have been presented: one of a man in whom the proximal fragment of the radius was sufficiently long to receive the central rod of the swivel; and the other of a woman in whom a longer segment of the proximal end of the radius had previously been resected, with the result that one end of the central rod of the metal prosthesis had to be doweled obliquely into the proximal portion of the ulna.

We have not had the opportunity to use this method in cases of proximal radio-ulnar synostosis of congenital origin. However, we see no reason why it should not succeed equally well in these cases, for functional restoration is attained with greater ease in younger individuals; also in congenital radio-ulnar synostosis the proximal fragment of the radius is not shattered and has not been surgically tampered with. Against this advantage there is the fact that bones in young individuals sometimes produce excessive callus which may grow over and bridge the gap occupied by the metal prosthesis. Minimization of the surgical trauma and use of a comparatively longer metal cylinder to span the gap created by the resected portion of the radius may eliminate this hazard. Needless to say, in younger individuals the girth of the cylinder portion of the prosthesis should be the same as that of the resected bone and the width of the central rod should not be much larger than the medullary cavity of the radius.

The Arteriographic Picture of Benign Bone Lesions Containing Giant Cells

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The purpose of this presentation is to introduce the possibility of a relationship between the arteriographic aspect and the number of giant cells present in three pathologically distinct benign bone lesions.

Peripheral arteriographic studies have demonstrated that the vascular pattern within and surrounding malignant bone tumors or soft-tissue neoplasms is essentially different from the pattern observed in benign tumors. These changes have been reported previously [1, 2, 3, 5, 7, 8, 9] and, therefore, are only briefly listed here. The characteristic arteriogram indicating malignant vascular changes may result from several factors such as:

1. Increased irrigation of the affected area by newly formed vessels;

2. Early venous return of the injected radiopaque substances (that is, the venous pattern proximal to the lesion can be demonstrated during the arterial phase while the contrast medium appears later in the distal veins of the extremity) — this suggests that some type of arteriovenous shunt exists at the level of the neoplasm;

3. Deviation and tortuosity of the main artery or of its branches in the vicinity of the tumor;

4. A peculiar type of striation similar to the spicule formation in osteogenic sarcoma which, in many instances, may be observed before the conventional roentgenograms reveal a definite neoplasm [2];

5. Puddling and retention of the radiopaque material in the affected area frequently extending over a prolonged period of time in the venous phase.

The vast majority of benign bone tumors are characterized by vascular patterns identical to those observed under normal conditions. There exists, however, a small group of benign bone lesions which have the tendency to retain radiopaque material but do not give evidence of any other of the arteriographic criteria of a malignant condition. It is the purpose of this paper to analyze the arteriographic findings in this group of bone lesions.

All primary bone and soft-tissue neoplasms seen at Roswell Park Memorial Institute during the past two years were evaluated by means of arteriography. The progression of the contrast substance was recorded by a rapid seriograph which made twelve roentgenograms at one-second intervals. The first film was always exposed immediately after completion of the injection of the radiopaque material. Hence, by employing this technique, a satisfactory comparative study of the arteriographic picture in the various tumors was made possible. In all injections 50 per cent urokon was used.

In a review of a series of sixty peripheral arteriograms, it was noted that three cases merited special consideration. The detailed angiographic studies were combined with careful histological evaluation of adequate biopsy material.

CASE 1. A twelve-year-old white girl was referred to the Institute with a one-year history of swelling and intermittent pain on the dorsum of the right foot. Any type of injury was denied.

Physical examination revealed a well nourished and well developed patient who had a slight, irregular swelling over the first cuneiform bone of the right foot without inflammation of the overlying tissues or local tenderness. The remainder of the physical examination was within normal limits.

FIG. 1-A

Case. 1. Roentgenogram of right foot showing an expansile, cystic lesion involving the entire first cuneiform bone (arrows). The cortical boundaries appear intact.

FIG. 1-B

Arterial phase of the femoral arteriogram. Except for a few, tiny, straight vessels of regular caliber leading to the lesion, there are no vascular abnormalities. The lesion remains radiolucent.

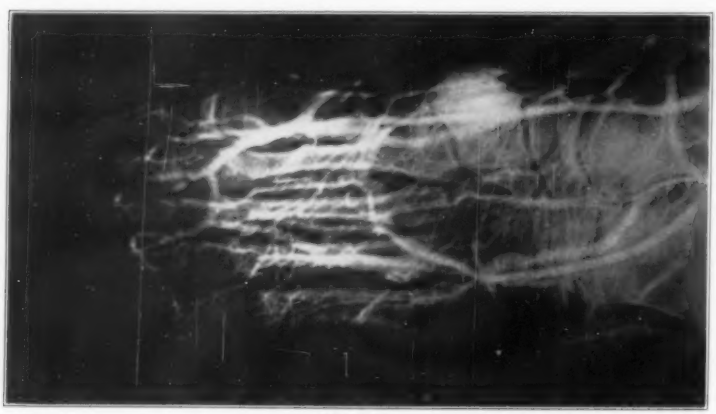

FIG. 1-C

Fig. 1-C: Late venous phase. Note the pronounced retention of contrast medium localized within the entire lesion. The remaining bones maintain their normal appearance.

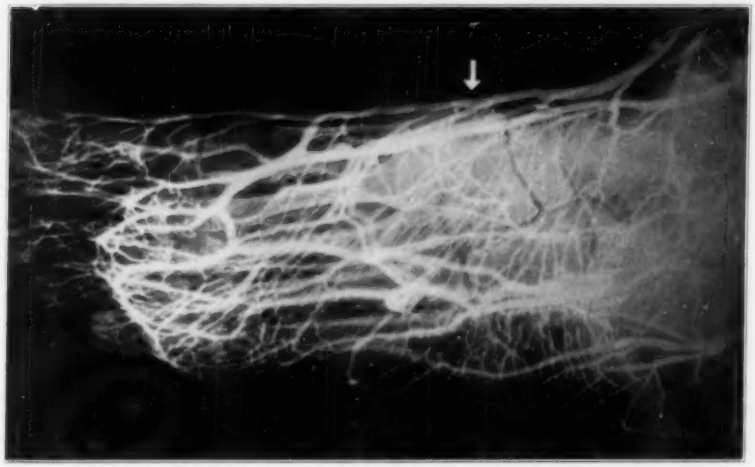

FIG. 1-D

Arterial phase of the femoral arteriogram made three months after operation reveals no abnormalities (arrow).

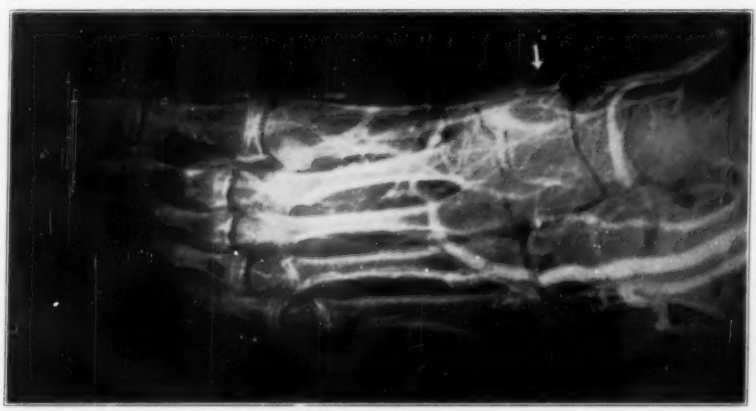

FIG. 1-E

Late venous phase. Three months after operation there was no retention of contrast medium (arrow).

Roentgenograms of both feet revealed the skeletal structures of the left foot to be entirely normal. On the right, however, there was an expansile, cystic lesion involving the entire first cuneiform bone. The normal bony trabeculations were absent, but the cortical contours appeared to be intact (Fig. 1-A).

Femoral arteriography was done. The arterial phase was not remarkable. No puddling of the contrast medium outside the bone or evidence of an arteriovenous fistula could be seen (Fig. 1-B). During the venous phase, however, the involved bone, in contradistinction to the surrounding bone structures, was completely and intensely radiopaque. The retention of contrast substance within the cystic cavity was apparently diffuse and persisted for an unusually long period of time; it was still present with the same intensity twelve seconds after injection (Fig. 1-C).

The involved area was explored surgically, the cavity was unroofed, and the lesion was thoroughly curetted and cauterized. The entire central portion of the bone was found to have been replaced by soft, mushy, brown tissue which on frozen section was classified as benign giant-cell tumor. The diagnosis was later confirmed by permanent sections. Femoral arteriograms were made three months after surgery; the angiographic abnormalities previously observed at the level of the first cuneiform bone were not present

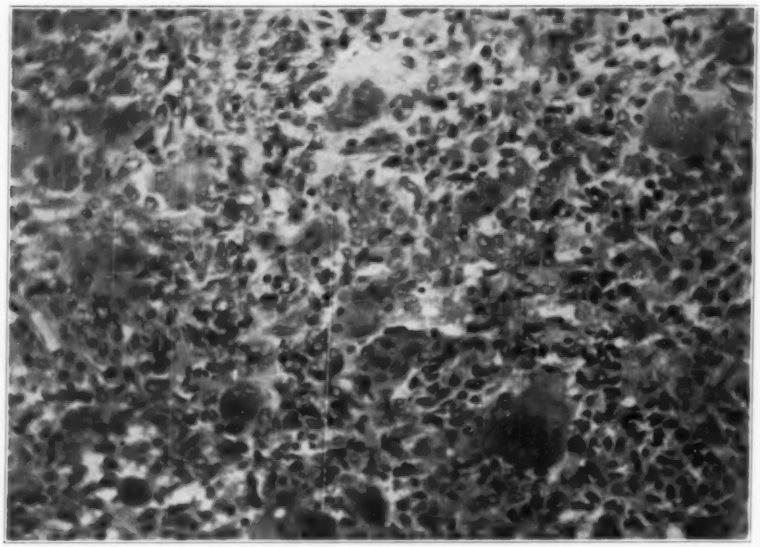

FIG. 1-F

Photomicrograph of specimen curetted from the cystic lesion of the first cuneiform bone. The slightly vascularized network of stromal cells contains abundant giant cells (× 350).

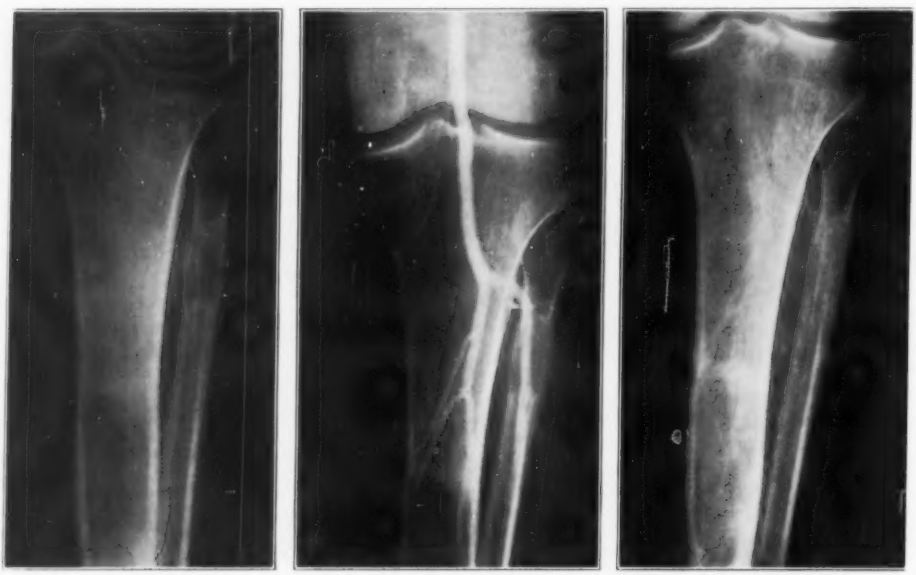

FIG. 2-A FIG. 2-B FIG. 2-C

Fig. 2-A: Case 2. Routine roentgenogram of the left lower extremity revealing rather well circumscribed osteolytic lesions involving the upper half of the tibia and fibula.

Fig. 2-B: Arterial phase of the femoral arteriogram. Normal vascular pattern.

Fig. 2-C: Late venous phase. The involved areas, which during the arterial phase remained radiolucent, exhibit diffuse retention of opaque medium.

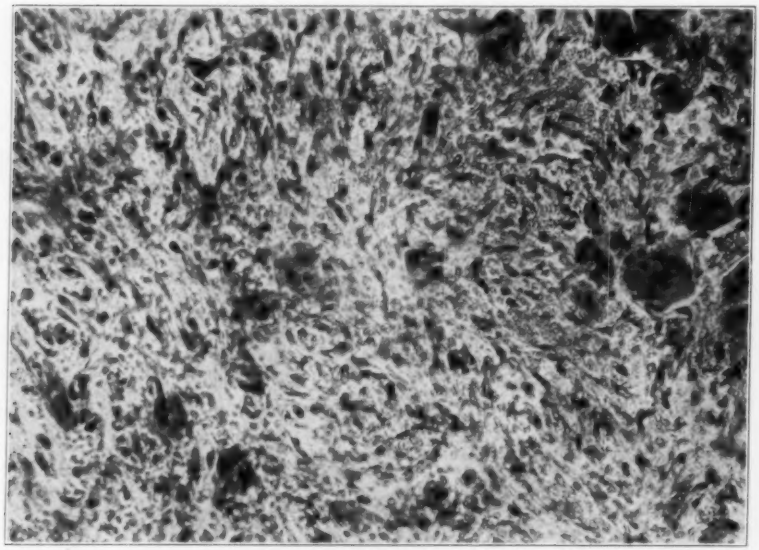

FIG. 2-D

Photomicrograph demonstrating typical histological changes of osteitis fibrosa cystica. The fibrous stroma is moderately vascular and interspersed with giant cells (× 350).

(Figs. 1-D and 1-E). Follow-up roentgenograms made nine months after operation showed no recurrence, and the patient was without symptoms.

Multiple sections of the benign giant-cell tumor show, according to Jaffe, Lichtenstein, and Portis, "a vascularized network of spindle-shaped or ovoid stromal cells regularly and heavily interspersed with multinuclear cells (apparently syncytial stromal cells) as an integral part of the cytologic pattern" (Fig. 1-F). The lesion was felt to be a true giant-cell tumor in spite of the young age of the patient. Of the three lesions discussed, this one contained the most giant cells, and it was far less vascular than the third lesion, but it retained the most contrast medium.

CASE 2. A white man, sixty-four years old, was admitted. His occupation as waiter called for the frequent placing of chairs around tables. This was done not only by lifting but also by guiding the chair with the left leg. Three months prior to admission to the Institute, there had been a slight dull ache in the left leg which had gradually increased in intensity. Some swelling was noted on the anterior and superior aspect of the left tibia. The patient had passed renal stones on four different occasions over a period of eight years.

The only pertinent findings on examination of this well developed and well nourished patient were limited to the neck and left leg. There was fullness in the region of both lower poles of the thyroid gland. The gland itself was slightly enlarged and multinodular. On the anteromedial aspect of the left tibia there was a fusiform swelling, eight centimeters long.

The clinical impression of hyperparathyroidism was confirmed by the presence of metabolic changes in the patient's blood and urine. The serum calcium and alkaline phosphatase levels were elevated while the titer of serum phosphorus was depressed. Results of the Sulkowitch test for calcium in the urine was + + +.

Roentgenographic survey of the skeleton revealed osteolytic lesions in the upper third of the tibia and upper portion of the fibula of the left leg (Fig. 2-A). Additional small radiolucent areas were observed in the right iliac bone and upper portion of the shaft of the right femur.

Femoral arteriography was done with the patient under local anaesthesia. The main arterial channels were well visualized and found to be normal. Extracortical new-vessel formation was absent (Fig. 2-B). During the venous phase, however, there was diffuse opacity of the radiolucent areas (Fig. 2-C). The retention of the contrast medium, although less pronounced than that in the previous case which was a true giant-cell tumor, was still observed on the last of a series of twelve roentgenograms made at one-second intervals. The over-all arteriographic picture was that of a benign tumor with a tendency to retain contrast medium during the venous phase.

In order to obtain an adequate biopsy specimen of normal as well as involved bone, a partial resection

FIG. 3-A FIG. 3-B FIG. 3-C

Fig. 3-A: Case 3. Routine roentgenogram showing an eccentric, radiolucent area in the upper third of the right tibia. There is evidence of slight periosteal elevation with a small soft-tissue mass.

Fig. 3-B: Arterial phase of the femoral arteriogram. The involved area remains radiolucent.

Fig. 3-C: Late venous phase. Note that only a portion of the entire lesion retains contrast medium. A circular area adjacent to and including the previously noticed soft-tissue shadow retains dye and the soft-tissue mass appears much better outlined (arrows). The remainder of the lesion has maintained its radiolucent appearance.

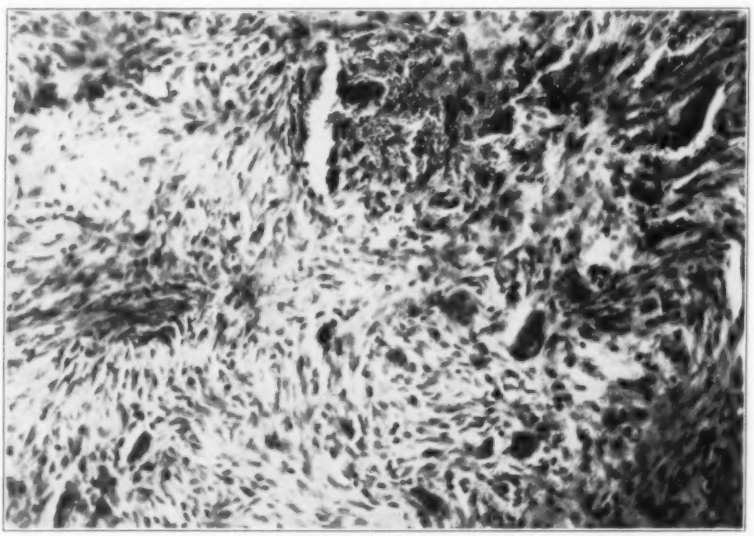

FIG. 3-D

Photomicrograph of specimen from the area showing dye retention. There are scattered areas of giant cells associated with areas of old hemorrhage (× 350).

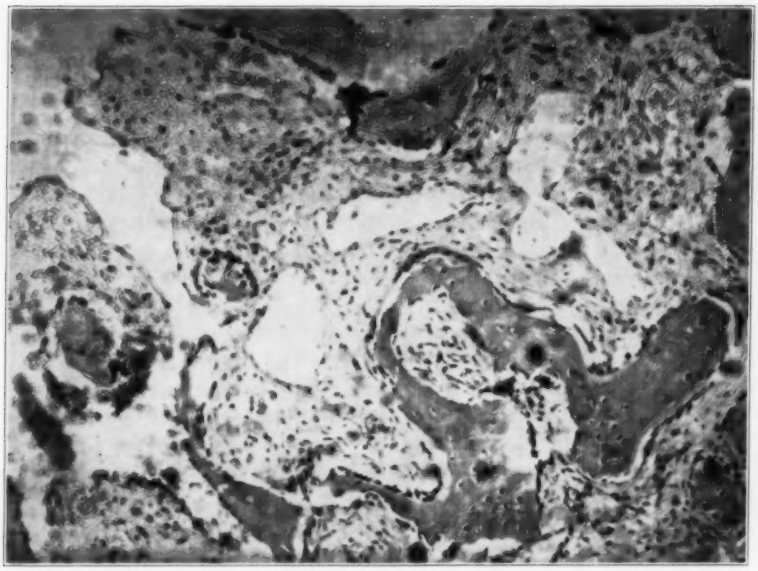

FIG. 3-E

Photomicrograph of the curetted material from areas of the lesion which did not retain contrast medium. There is a striking difference between this photomicrograph and that shown in Fig. 3-D; there is an absence of giant cells in a similarly fibrous stroma and there are much larger vascular spaces (× 145).

of the upper half of the left fibula was carried out. Grossly, the involved area measured twenty-five by ten by fifteen millimeters. The bone marrow was entirely replaced by well circumscribed reddish-brown, soft, friable tissue. The cortex was thinned out but was intact. Microscopically, the sections showed areas of giant cells in a relatively fibrous, moderately vascular stroma, a picture characteristically associated with the osteitis fibrosa cystica of hyperparathyroidism (Fig. 2-D).

Upon exploration of the patient's neck, two enlarged lower parathyroid glands were encountered and were removed in continuity with portions of the nodular goiter. The right parathyroid gland weighed fifteen grams and the left weighed five grams. The Sulkowitch test for calcium in urine became negative on the first postoperative day and remained negative thereafter; the serum calcium and alkaline phosphatase levels rapidly and permanently regressed to normal levels.

CASE 3. A fifteen-year-old white male was hospitalized at the Institute with a history of injury to his right leg approximately five weeks prior to admission. An area on the anterosuperior edge of the tibia became increasingly tender and swollen. He began to limp.

The only pathological finding on physical examination consisted of a slight swelling of the anteromedial aspect of the right tibia which was firm and tender. A complete roentgenographic skeletal survey revealed a zone of radiolucency in the upper third of the right tibia. This lesion was eccentrically located and was surrounded by a slight degree of periosteal reaction, as well as by a small soft-tissue shadow (Fig. 3-A).

Femoral arteriography was done. After the injection of thirty cubic centimeters of a 50 per cent solution of urokon, no abnormal new-vessel formation was detected during the arterial phase (Fig. 3-B). There was, however, a slight, but definite, retention of contrast medium during the entire venous phase. This retention was still present on the last of the series of twelve films. The increased radiopacity appeared to be localized within a small circular area adjacent to and including the soft-tissue shadow while the rest of the lesion remained radiolucent (Fig. 3-C).

Upon exploration, the lesion was found to consist of two cystic cavities. The superficial one showed disruption of the cortex by a cyst without evidence of infiltration of the soft tissues. The soft tissues appeared merely displaced by the expanding mass. Both cavities were unroofed, curetted, and cauterized. The contents were submitted separately to the pathologist (H. C. S.). The content of the more centrally located cavity had a yellowish-gray appearance and firm consistency. The curetted material from the superficial cyst was brownish-red, friable, and spongy in places.

Histologically, the sections from the area showing retention of contrast medium on arteriography contained scattered focal areas of giant cells associated with areas of hemorrhage and hemosiderin pigmentation (Fig. 3-D). The sections from the deeper area of the lesion, which did not retain contrast substance, showed

no giant cells but had the same amount of fibrous tissue with markedly vascular spaces (Fig. 3-E). The entire lesion was felt to be a so-called aneurysmal bone cyst [6].

DISCUSSION

The arteriographic pictures obtained in these three benign bone lesions containing giant cells showed interesting peculiarities. Vascular changes during the arterial phase, such as are seen in malignant tumors, were not observed in any of the three cases studied. It was only during the capillary and especially the venous phase that retention of contrast medium within the affected area or parts of it was demonstrated. These three lesions, in other words, exhibited an arteriographic pattern which as a whole mimicked that seen in normal conditions, except for the accumulation of contrast medium within the lesion during the venous phase.

Comparison of the histological data with the arteriographic observations in the three lesions suggests that the intensity of the observed arteriographic changes parallels the concentration of giant cells both in quantity and location rather than the relative vascularity of the lesions. In this respect, it appears that the degree of vascularity, which may not be identical with the rate of blood flow, has little effect upon the retention of the contrast medium within the lesion. If such were the case, it would be logical to assume, in contradistinction to the submitted observations, that the most vascular lesion (aneurysmal bone cyst) would evidence the highest degree of radiopacity following the injection of contrast medium while the least vascular lesion (giant-cell tumor) should remain radiolucent. We do not claim the specificity of urokon * for the production of arteriographic patterns since similar angiographic changes have been observed with thorotrast ** by Caldos. It is nevertheless interesting that the ability of these lesions to retain contrast medium appears independent of their different etiology, that is, neoplastic, metabolic, and reactive.

The very same observations, furthermore, confirm the previously expressed opinion that the point has not yet been reached when the histological nature of a bone or soft-tissue tumor can be determined merely by changes affecting the arteriographic architecture within or around such lesions [7, 9]. Further investigative work will be required in order to evaluate the influence which additional factors such as the rate of neoplastic growth, intimate vascularity, and rate of blood flow within the tumor may have upon the development of certain arteriographic patterns.

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* Urokon is chemically the sodium salt of 3- acetylamino-2, 4, 6-triiodobenzoic acid.

** Thorotrast is chemically a 25 per cent solution of thorium dioxide mixed with aqueous dextrin and 0.15 per cent methyl parasept as a preservative.

Experimental Studies Regarding the Possible Use of Self-Curing Acrylic in Orthopaedic Surgery

BY L. L. WILTSE, M.D., R. H. HALL, M.D., LONG BEACH, AND
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Methyl methacrylate, an acrylic plastic, has been used for many years in medicine and especially in dentistry. The clear plastic which is used in the Judet prosthesis is methyl methacrylate.

It has been known for many years that this clear material can be obtained by mixing a white powder, a polymer, with a colorless liquid, a monomer. When the powder and the liquid are mixed, a soft doughy mass results which, when heated, forms a clear hard material.

The main difference between self-curing plastic and heat-cured plastic is that, in the self-curing, there has been a catalyst added to the powder and an accelerator added to the liquid so that it is not necessary to have external heat applied to bring about polymerization and, thus, hardening of the material. All that is necessary is to mix the powder and the liquid together to form a creamy mass and, in a few minutes, it will be set hard.

The catalyst in the powder is benzoyl peroxide in the amount of approximately 0.1 to 0.6 per cent, and the accelerator in the liquid is a very small amount of a tertiary amine. The larger the amount of catalyst and accelerator, the faster setting will occur.

The polymer is a fine white powder and the monomer is a clear watery liquid. When these two are mixed, a creamy substance results. This remains creamy for a short time, becomes doughy, rubbery, and then sets hard. The speed of each step depends upon the amount of catalyst and accelerator, the ratio of powder to liquid in the mix, and the surrounding temperature.

Since July 1952, we have experimented with this self-curing plastic to see what uses, if any, it might have in orthopaedic surgery. The following were listed as possible applications:

1. Building up a metallic prosthesis to fit more snugly in bone;
2. Filling bone cavities as, for instance, a large cyst near the end of a long bone in an old person;
3. In depressed fractures of the tibial condyle;
4. Making prostheses for replacement of portions of joints;
5. Increasing stability in spine fusions and permitting early pain-free ambulation.

One use of the plastic outside the scope of orthopaedic surgery was investigated, namely, the filling of cranial-vault defects.

When we first started this work, we were unaware that any other work had been done with this material. Since that time, however, two articles on the use of self-curing acrylic have appeared in the literature [1, 2].

Henrichsen, Jansen, and Krough-Poulsen tested self-curing acrylic in young pigs to see if there was tissue reaction; they found no reaction at autopsy or by roentgenography or histological study. Spence used self-curing acrylic to fill cranial-vault defects with success.

MATERIALS

Plastic of various setting speeds was used in rabbits and monkeys. By varying the amounts of catalyst and controlling the temperature, we were able to defer the setting up to one and a half hours or to speed it up to three or four minutes. The plastic which we believe best suited for most purposes sets in about ten minutes.

TABLE I

Time in Minutes	Degrees Fahrenheit	Consistency of Material
0	93	Thin cream
1	93	
2	93.5	
3	94	Thick cream
4	95.5	
5	98	Rubbery
6	100	Hard rubber
7	103	
8	108.5	Very hard rubber
9	129	
10	175	Set
11	160	
12	144	
13	134	
14	127	
15	120	

An impression material is available which is cheap and easy to handle. It can be sterilized in an ordinary autoclave. Making the negative mold takes about one and a half minutes and can be done on a sterile operating-room table.

PROPERTIES OF THE PLASTIC MATERIAL

In the polymerized state, this self-curing material is usually not clear but translucent. The reason that it is not clear (as lucite is) is that air becomes trapped in the mixed material. If pressure is applied while the plastic is setting, the resulting mass will be clear.

Strength

This acrylic resin is similar in strength to that used in Judet femoral-head prostheses, which is heat-cured resin but not quite as strong. From the standpoint of transverse strength, a bar of this material 4.63 millimeters in diameter is as strong as a bar of heat-cured resin 4.38 millimeters in diameter. Both will withstand 10,600 pounds per square inch crushing force, and both will be crushed by 12,000 pounds per square inch. Knoop hardness tests show self-cured resin to be 15.6, while the heat-cured resin is 18.

It is difficult to compare the hardness of plastic with that of Vitallium or stainless steel since they are such entirely different materials. Both metals are very much harder than acrylic, probably in the neighborhood of ten or twelve times as hard; likewise, the strength is very much greater. Vitallium has a yield tensile strength of 75,000 to 85,000 pounds per square inch and an ultimate tensile strength of 95,000 to 110,000 pounds per square inch. The hardness of Vitallium on the Rockwell C scale is 30 to 35. Surgical stainless steel has various hardnesses. The softest type, as measured on the Rockwell B scale, is 80 to 85. There is, then, the one-quarter hard, the one-half hard, the three-fourths hard, and the hard. On the Rockwell C scale, the one-quarter hard is 20 to 25 and the hard, 30 to 38. The properties of stainless steel are quite different from those of Vitallium, and simple comparisons of hardness or yield strength do not give a true picture of usefulness.

Heat of Polymerization

Just as the material sets, the temperature rises sharply. This hot phase lasts less than a minute. The rise in temperature is due to heat of polymerization and is an essential part of the reaction.

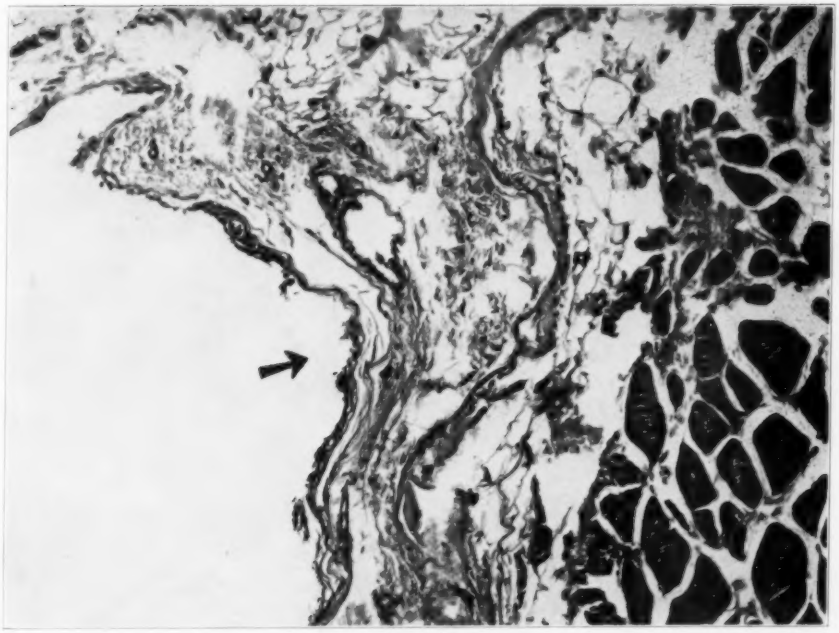

FIG. 1-A

Photomicrograph of muscle which had been in direct contact with acrylic in a rabbit for six months (× 55). In all photomicrographs arrow indicates area of contact between acrylic and tissue.

FIG. 1-B

Photomicrograph of bone which had been in direct contact with acrylic in a rabbit for six months (× 64).

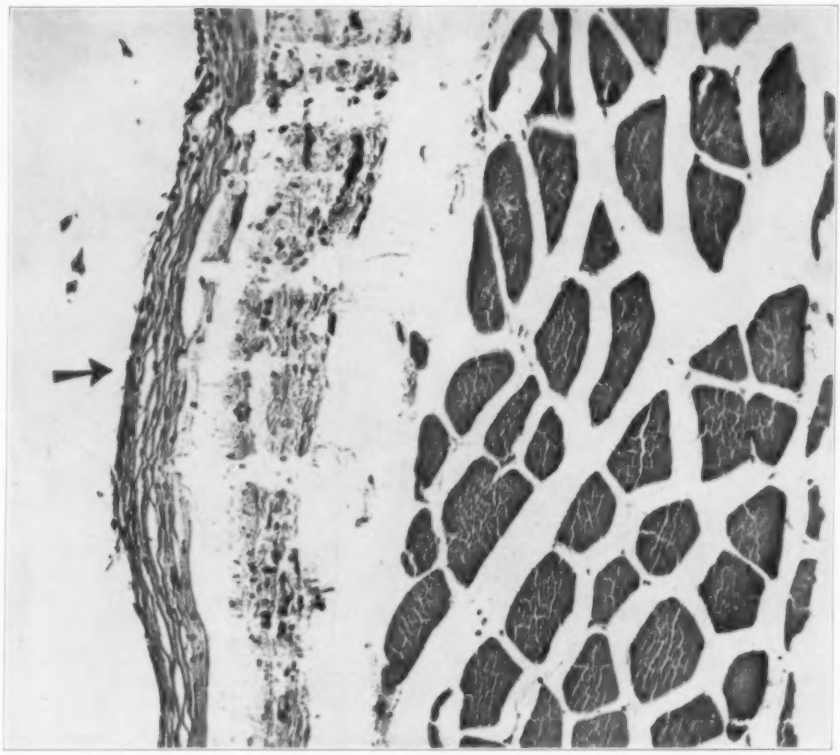

FIG. 2-A

Photomicrograph of muscle which had been in direct contact with Vitallium in a rabbit for six months (× 64).

By means of a thermocouple, determinations were made of the rise in temperature at the point where the material touched the bone when the lower one-half of the femur was filled with plastic. At the point where the measurement was made, the inside diameter of the femur was three-fourths of an inch. The temperature rise is recorded in Table I, sterile plastic which set in ten minutes having been used. Body and operating-room conditions were duplicated as nearly as possible. The bone had been soaked in saline for twenty-four hours prior to the test and, at the time that the test was made, the bone was in a water bath kept at 98.6 degrees Fahrenheit. The materials were mixed at room temperature as they would be in the operating room.

It must be noted that marked variation in the temperature rise will occur depending on conditions. The size of the mass, the speed of setting, and the rapidity with which heat is dissipated are the controlling factors. In a mass of material one-fourth of an inch in diameter the heat of polymerization will not rise more than 15 degrees Fahrenheit in the open air; but, if it is enclosed in a non-conducting material, there will be a rise in temperature great enough to damage tissue. By running ice water over the material as it sets, the temperature at the surface of a mass three inches in diameter can be kept down to a safe level.

Slowing down the setting time is not the answer to the heat problem, since it is at the moment of polymerization that the heat is given off and, even if the setting time is slowed to one and a half hours, the heat of polymerization will remain much the same.

Heat is, with the acrylics studied, a troublesome factor whenever masses greater than

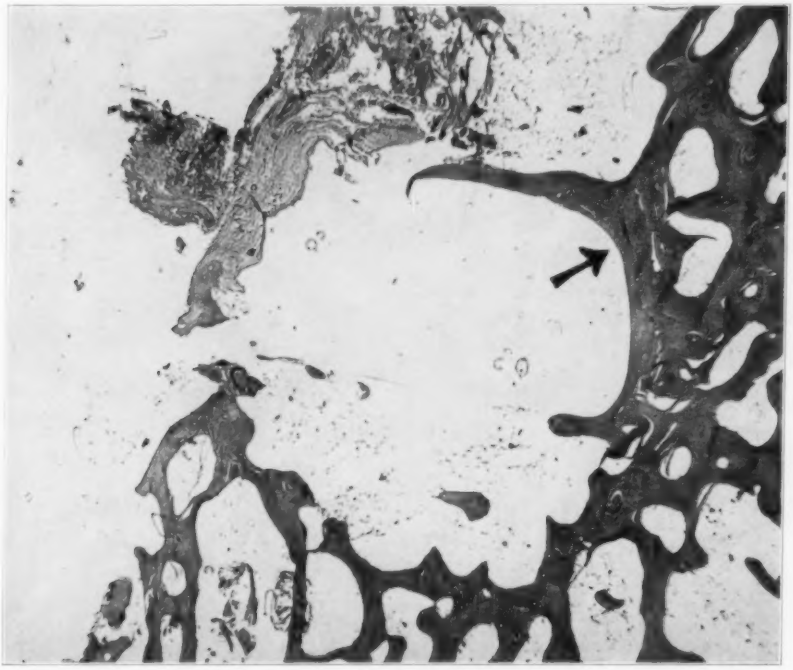

FIG. 2-B

Photomicrograph of bone which had been in direct contact with Vitallium in a rabbit for six months (× 64).

one-fourth to one-half inch in diameter are used. At present, the most practical way to control the heat is to permit polymerization to occur out of contact with tissues. This can be done by use of the mold-and-casting process away from the surgical field on a sterile side table, or by molding the plastic in the wound and removing it during the maximum heat phase of polymerization. The replica produced by either process can be coated with one or more thin laminae of new plastic to make it fit solidly.

Sterilization

A system of sterilizing both the powder and the liquid was developed which does not cause chemical change in the material. The material is available in convenient sterile packages which can be stored easily and without deterioration for long periods.

Tissue Tolerance

In checking for tissue tolerance, Vitallium was used as a standard for comparison. Acrylic was placed in the soft state in one thigh of a rabbit and Vitallium in the other. Approximately fifty rabbits were used. These animals were sacrificed at intervals up to a year, and microscopic studies were made of adjacent tissues. There was no more tissue irritation from the acrylic (Figs. 1-A and 1-B) than from Vitallium (Figs. 2-A and 2-B) in either soft tissue or bone, provided that no fragmentation of either substance occurred. Fragmentation ordinarily did not occur in the plastic if it were put in properly. If, when it was injected, it went into thin layers or was mixed with blood, it might fragment.

Effect of Large Masses on Liver and Kidneys

Tests were made to determine if, when large masses of the material were put into the animal body in the liquid state, there were deleterious effects on the liver and kidneys.

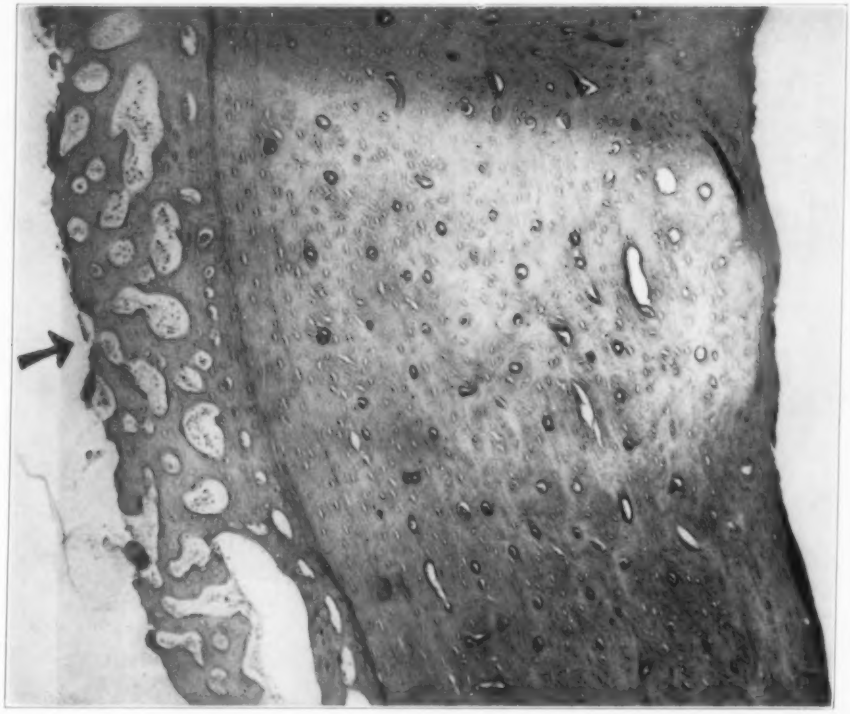

FIG. 3

Section of femur nine days after filling with acrylic (× 50). Note zone of subperiosteal remodelling.

A series of rabbits were used. It was thought that possibly absorption of toxic monomer would cause detectable changes. These rabbits were sacrificed at intervals. No deleterious effect was noted even when as much as an ounce of material was used. This would compare to almost two pounds in a human being weighing 150 pounds.

Filling of Medullary Canals of Long Bones

The medullary canal of one femur was completely filled with acrylic in a series of twenty-one rabbits. This was done by making an opening about 0.5 centimeter in diameter on the outside of the lateral femoral condyle. All marrow was removed and the cancellous bone of the condyles was curetted out. Plastic was poured in. The entire canal was filled. Roentgenograms were made at intervals and the rabbits were sacrificed. The mass of acrylic in the medullary canal was small enough so that the heat would not cause necrosis of the femoral shaft.

The following observations were made:

1. A zone of reaction about 0.5 millimeter in thickness occurred underneath the periosteum and was noted at between one and two weeks. This was not present in rabbits killed after two weeks (Fig. 3).

2. At first, the plastic was right against the bone, but later a layer of hematopoietic tissue developed between the plastic and the bone. This varied in thickness up to one millimeter (Fig. 4).

3. As seen by roentgenograms, the bone appeared to remain normal. Comparative roentgenograms of the two femora were so much alike that we could not tell by roentgenogram alone which was filled with plastic and which was not, even after seven or eight months (Fig. 5).

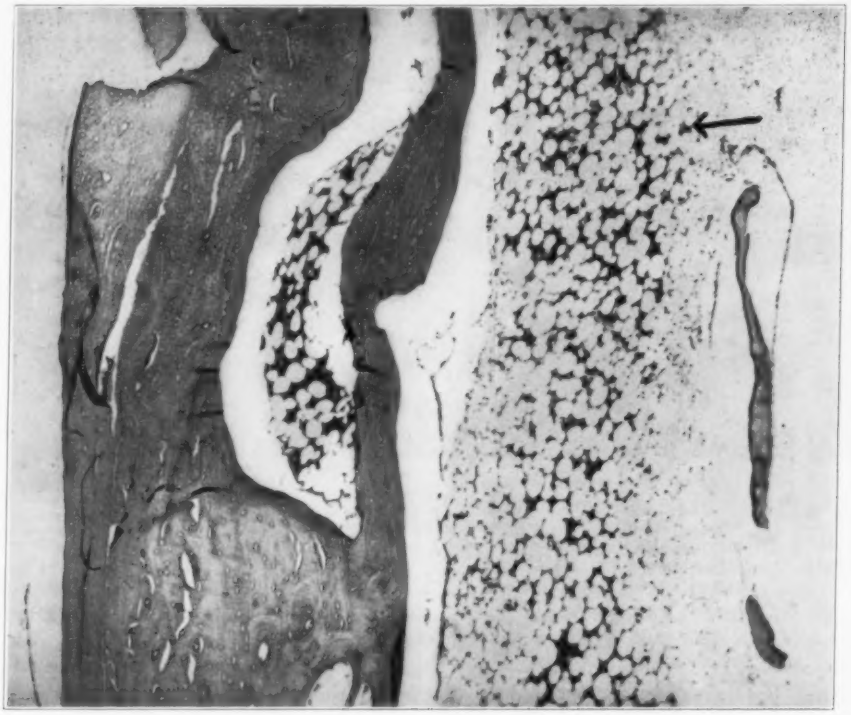

FIG. 4

Section of femur nine months after filling with acrylic (× 39). Note hematopoietic tissue between the plastic and the cortex.

FIG. 5

Roentgenogram of both hind limbs of rabbit. Right femur was filled with acrylic nine months ago. There is no perceptible difference as seen roentgenographically between the two.

FIG. 6

Roentgenogram of both hind limbs of a rabbit. Two cubic centimeters of 75 per cent neo-iopax was injected directly into the marrow of the medial condyle of both femora. The right femur had been filled with acrylic. Note the large amount of dye in the medullary canal on the left; this is not present in the acrylic-filled femur on the right.

4. In three animals in which the medullary canal was completely filled, a visible ring of necrosis about one millimeter in width occurred in the middle of the femur. This happened during the first two weeks in each case. This was presumed to be due to failure of circulation in this area. However, in none of the other rabbits did this occur. This prompted us to inject the marrow of the femoral condyles with two cubic centimeters of 75 per cent neo-iopax (a radiopaque solution) in both a normal and a filled femur in three animals. Figure 6 is a roentgenogram of a rabbit's femora after the injection of neo-iopax; the right femur had been filled with acrylic.

Circulatory studies were not pursued any further because they were outside the main purpose of this project; however, it was believed that the plastic offers possibilities in the study of circulatory changes in long bones after completely or partly filling the medullary canals.

Trueta and Cavadias have made some excellent studies of the vascular changes caused by filling the medullary canals of the radii of rabbits by Küntscher-type nails.

REPLACEMENT OF PARTS OF THE ELBOW JOINT

Plastic was used in making replicas of various parts of the elbow joint in monkeys. The results of these replacements of plastic were compared with similar replacements of Vitallium. No essential difference could be detected as regards function or tissue irritation.

Some interesting observations were made from these replacements of parts of the elbow joint. It was found that any part of the elbow could be replaced with a perfect plastic replica simply by taking out from the normal joint any part, making a negative mold in the impression material, and then casting the replica. A stem would then be put into the replica while it was setting, and the replica put into the joint as a prosthesis (Fig. 7). Vitallium replacements were made in much the same manner; these, however, took several days to make (Fig. 8).

In nearly every animal in which the ulna or the humerus at the elbow was replaced, whether with Vitallium or plastic, the monkey would have very good motion in his elbow for the first few weeks. Gradually the joint would freeze and most or all motion would disappear after three or four months, even though great care was used to remove all

FIG. 7

FIG. 8

Fig. 7: Roentgenogram of elbow of a monkey six weeks after operation. The lower end of the humerus has been replaced with a plastic prosthesis with a metal stem.

Fig. 8: Roentgenogram of elbow of a monkey four months after operation. The lower end of the humerus has been replaced by a Vitallium prosthesis. Note that bone is beginning to form across the joint area. This formed just as readily whether Vitallium or plastic was used.

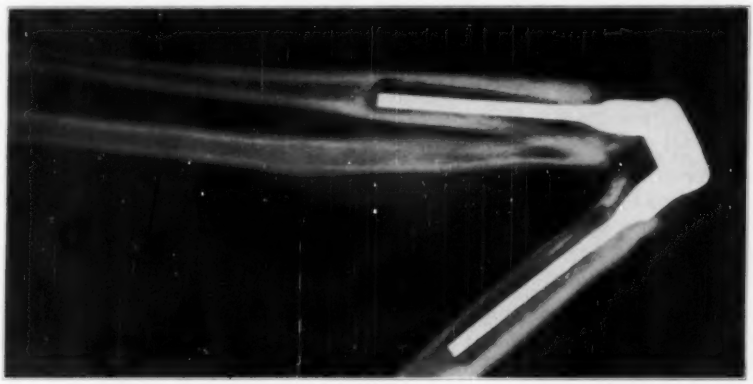

FIG. 9

Roentgenogram of elbow of a monkey one month after operation. The lower end of the humerus and the upper end of the radius and ulna were removed. A stainless-steel mechanical joint was inserted. The stems were surrounded with plastic, which accounts for the clear area around each stem.

periosteum in order to minimize new-bone formation. When only the radial head was replaced, motion was retained.

In animals in which parts of the joint had been destroyed so that there was no model to use in the making of a plastic replica, it was found that there are several types of wax which can be fashioned easily with a scalpel into the proper shape. This wax can be made sterile and can be used right at the operating table.

When replacement of parts of the elbow joint was compared with replacement of the femoral head, it was noted that, while stiffness always occurred sooner or later at the elbow, good motion was retained in two of three hips. This might be due, possibly, to the larger muscles and better mechanical advantage of the muscles at the hip.

FIG. 10

Roentgenograms of the left femur of a monkey made three years after operation. A gap of about one and a half inches was filled with plastic reinforced with a metal rod. New bone nearly surrounded the gap.

Complete replacement of the elbow with mechanical joints was done in six monkeys. The stems were bonded into the medullary canals of the humerus and the ulna with plastic (Fig. 9). These worked well at first, and motion was good. Gradually, over a period of four or five months, complete ankylosis occurred in every animal.

BRIDGING GAPS IN BONE

A one and one-half inch cylinder of bone was resected from the femur in a monkey, and the gap was filled with acrylic with a small stainless-steel Steinmann pin core which was used as an intramedullary nail to reinforce the plastic. The monkey was turned loose as soon as he recovered from anaesthesia and seemed to have no difficulty over the next three years. New bone almost completely surrounded the plastic area (Fig. 10).

MAKING NEW JOINT SURFACES

New joint surfaces were made from plastic by making a plastic inlay which was rubbed smooth as it hardened and which was polished, if necessary, with a buffer on a small motor tool. Because of the difficulty in polishing, the lack of strength in the material, and the immediately adjacent membrane of soft tissue which formed between the inlay and the bone, these new joint surfaces did not work well experimentally.

SPINE FUSIONS WITH ACRYLIC

Several spine fusions were done in the rabbit with acrylic. In these animals, an area of about four vertebrae in the lumbar region was fused by making the lamina and spinous processes bare, as is commonly done in the usual spine fusion; no feathering of the bone was done. Two fairly large Kirschner wires were placed along each side of the spinous processes for reinforcement, and creamy plastic was poured into the area one-half inch thick incorporating the upper surfaces of the laminae, the spinous processes, and the

wire reinforcement. The fusions were solid at first, but because we were never able to control heat of polymerization adequately, the bone adjacent to the plastic became necrotic and the spinous processes which were in the plastic became soft in a week or so, and the fixation was lost. Even if the heat had been controlled, it is highly questionable if fixation would have remained solid, because in these animals the spinous processes were the main points of fixation and were completely surrounded by plastic except at their bases. It was not believed that they would remain viable when so nearly completely embedded in non-living material.

The results of the spine fusions were inconclusive, but it can be stated that they were generally unsatisfactory.

FITTING THE STEMS OF PROSTHESES TO BONE

When prostheses with stems were used, frequently plastic was poured into the open end of the medullary canal and the stem was pushed into the plastic. This produced a mass of material the size and shape of the medullary canal which was bonded to the stem, thus preventing rotation or pulling out. This material bonds very tightly to a rough metallic surface if it can pass completely around it, as is the case with the stem of the prosthesis.

FILLING CRANIAL-VAULT DEFECTS

Cranial-vault defects were filled with plastic in the monkey. Both tables of the skull were removed down to the dura. The defects varied in size from one-half to one and one-half inches in diameter. In filling these defects, the opening was first lined with aluminum foil and plastic was poured in and was smoothed with the fingers. When the plastic had reached the hard, rubbery stage, it was lifted out along with the foil and allowed to pass through the hot phase on the table. This takes only a minute or two. The foil was pulled off, and a small quantity of soft plastic smeared around the edge, and the plate was put back into the defect in the skull. This method avoided any danger of heating the brain tissue and also kept the plastic from adhering to the underlying tissues. The small amount of soft plastic added around the edge does not produce enough heat to be of any consequence. These plastic plates were kept in place by undercutting the bone in places much as dentists do to hold fillings in place.

The plastic seemed to work very well for filling cranial-vault defects. We inspected two of these several months after surgery, and they were still held snugly in place, and no adverse reaction was present in the underlying tissues.

CONCLUSIONS

1. Self-curing methyl methacrylate causes no more tissue reaction than does Vitallium in the rabbit or monkey.

2. It is not strong enough to be used without reinforcement where there is transverse stress. The strength seems adequate to withstand most compression stresses in the body. Strength is a limiting factor, however.

3. It can be obtained sterile and is available in convenient packages which can be stored for long periods.

4. Heat of polymerization is, at present, a troublesome and limiting factor. It can be controlled by various methods, but this adds to the inconvenience of using the material.

5. It can be molded quickly and easily by use of a negative mold.

6. It will not remain absolutely tight against the bone. This applies not only to plastic but also to steel and Vitallium.

7. Although at the present time, no uses in orthopaedic surgery can be recommended unequivocally, it is believed that it may find a place following more research on the basic material, especially as regards the heat of polymerization.

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Metastasis of Pulmonary Carcinoma to the Phalanges of the Hand

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Lung carcinoma is known for its unusual tendency to metastasize. One author reported that in a series of 1,023 cases metastases were found in 35 per cent of the patients and that of the 298 metastatic lesions of which the site was known, 8 per cent were in the

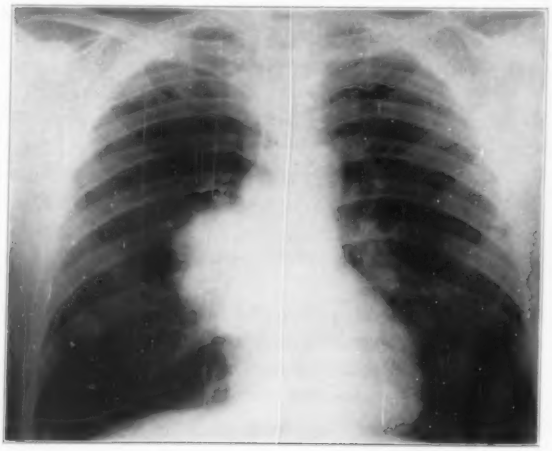

Fig. 1-A

Fig. 1-B

Fig. 1-A: Roentgenogram of the lung made prior to pneumonectomy.
Fig. 1-B: Roentgenogram of the metastatic tumor of the middle finger.

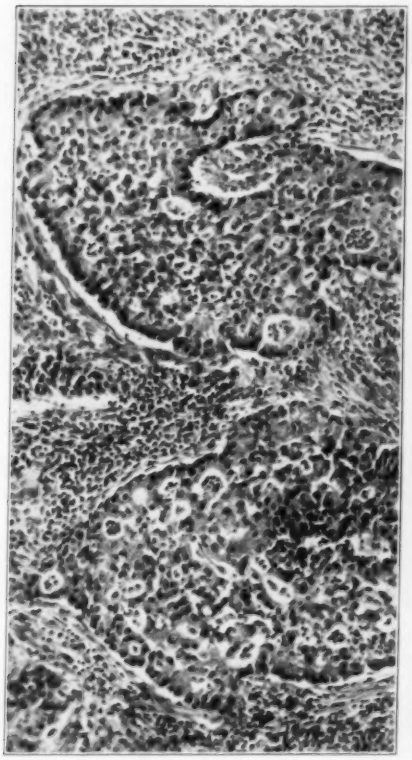

FIG. 2-A

FIG. 2-B

Fig. 2-A: Photomicrograph (× 90) of the pulmonary lesion.
Fig. 2-B: Photomicrograph (× 90) of the phalangeal lesion.

extremities[6]. Because of an apparent increase in lung cancer, metastatic lesions in the extremities may also become more common.

The literature contains few case reports of pulmonary metastasis to the hand. Indeed, reports of metastases to the hand from any lesion are rare. In the author's review of the literature, he found only ten detailed case histories of pulmonary metastatic lesions in the digits of the hand[1-5, 7, 9-11].

A phalangeal metastatic lesion may appear as a localized area of infection. Swelling, redness, and tenderness are the usual complaints. Not until treatment has failed and the results of biopsy have been obtained can the diagnosis be definitely made. In some cases, clinical evidence of phalangeal metastasis has been present before any pulmonary symptoms have been found[2, 9], and one author reported that in 12 per cent of fifty patients with lung carcinoma the disease completed its entire course without any pulmonary symptoms becoming apparent[8].

The last known report of a metastatic lesion in the hand was made in 1953[1]. Another case history is being added to the literature in this report.

On January 30, 1951, resection of the right lung was performed on a male Negro laborer, thirty-four years old, for Grade 3 bronchogenic adenocarcinoma (Figs. 1-A, 1-B, and 2-A). The results of the surgery were excellent, and the patient returned to work.

Four months after surgery, the patient entered the Los Angeles County General Hospital because of pain and some loss of motion in the right middle finger. This was his only complaint.

Examination revealed a localized tender area on the volar surface of the middle finger at the level of the

FIG. 3

Roentgenograms of the hand made three months after reconstructive surgery.

proximal joint. Slight swelling was present, but no definite mass was felt. The range of flexion was decreased. Roentgenographic study revealed a radiolucent area at the proximal end of the proximal phalanx. The findings of the laboratory studies were not unusual.

At surgery, a soft grayish mass the size of a grape was found to have invaded the volar cortex of the phalanx near the proximal joint. The flexor tendons were expanded volarly over the mass, and the cartilage of the joint was invaded. The third ray was amputated at the metacarpophalangeal joint, and the second ray was transplanted to the base of the third metacarpal in order to prevent crisscrossing of the fingers. Microscopic studies of the mass demonstrated that it was a metastatic pulmonary lesion (Fig. 2-B).

Three months later the patient had a good functioning hand without pain (Fig. 3). Eight months after the onset of the finger symptoms, however, the patient died, apparently as a result of cerebral metastasis. No autopsy was performed.

The average length of survival following the first appearance of symptoms in the reported cases of finger metastasis has been sixty-eight days. The longest period was 258 days (in this case) and the shortest period, nine days. Because patients with phalangeal metastasis survive for so short a time, it is doubtful that any reconstructive hand surgery should be done. Removal of the lesion in order to relieve pain and thus restore hand function is the only purpose of surgery.

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Bilateral Arborescent Lipoma of the Knee

A Case Report

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A nineteen-year-old girl came to the Clinic on June 30, 1953, because of swelling of both knees (Figs. 1-A and 1-B). The first symptoms had appeared when she was nine years old. At that time, without any known trauma, the left knee had gradually become swollen. She had had little pain, and her temperature had been 101 degrees. The temperature had returned to normal in about ten days, but the swelling had continued to increase. Aspiration had to be done every one or two months, but each time there had been a rapid recurrence of the symptoms with a steady increase in the amount of fluid and in the degree of swelling. Living in a small village, she did not seek further advice, and the aspirations had been continued for almost ten years.

In 1950, similar symptoms had appeared in the right knee.

When the swelling had become intolerable, the patient reported to the Clinic for treatment. Examination revealed that the swollen left knee was fifty-nine centimeters in circumference, the swelling extending up to the mid-thigh. The right knee was slightly smaller, being fifty-two centimeters in circumference. There were no other signs of local inflammation, and palpation of the knee indicated that the capsule was very thick walled and contained fluid held under tension. There was abnormal anteroposterior and lateral mobility of both joints, and roentgenograms revealed hypertrophic arthritic changes, areas of calcification (especially posterior to the femoral condyles), and lateral subluxation of the

FIG. 1-A

FIG. 1-B

Preoperative photographs.

FIG. 2-A

FIG. 2-B

FIG. 2-C

Fig. 2-A: Preoperative lateral roentgenogram of the right knee, made August 27, 1951.

Figs. 2-B and 2-C: Preoperative lateral roentgenograms of both knees, made July 2, 1953. The swelling of the soft tissues is evident.

left tibia (Figs. 2-A and 2-B). Extension was almost normal on the right side but was 15 degrees less than normal on the left side, probably as a result of the posterior subluxation of the tibia. Flexion was limited to between 110 and 100 degrees, depending on the amount of fluid present.

FIG. 3-A

FIG. 3-B

Postoperative photographs.

On July 15, 1953, aspiration of the left knee was performed and 1,300 cubic centimeters of yellowish, translucent, odorless fluid was removed. The swelling recurred during the next few days, and on July 22, 1953, an operation was performed on the left knee with the patient under general anaesthesia. A lateral parapatellar approach was used. As a result of the prolonged pressure exerted by the fluid, there was practically no subcutaneous tissue and the atrophied muscles formed only a thin layer. By blunt dissection, the distended capsule was approached and separated. Following incision of the capsule, a large amount of fluid, resembling exactly that obtained by aspiration, poured out of the opening. The capsular wall was thick, and its inner surface was covered with hypertrophic yellowish villi. These villi varied in size, the largest being about two centimeters long, and they were racemose in appearance, as is well shown in Figure 4. There was not a single area of the capsule which was not covered with villi. The cartilage of the femoral and tibial condyles was eroded, and the menisci were rather loose. A small area of calcification was present on the posterior portion of the condylar capsule. The entire capsule was removed, the posterior surface of the patella was trimmed, and the wound was closed in layers. A pressure dressing with elastic bandages was then applied. The patient's recovery was normal. She was up and around on the twelfth day and was discharged on August 7, 1953, fifteen days after the operation.

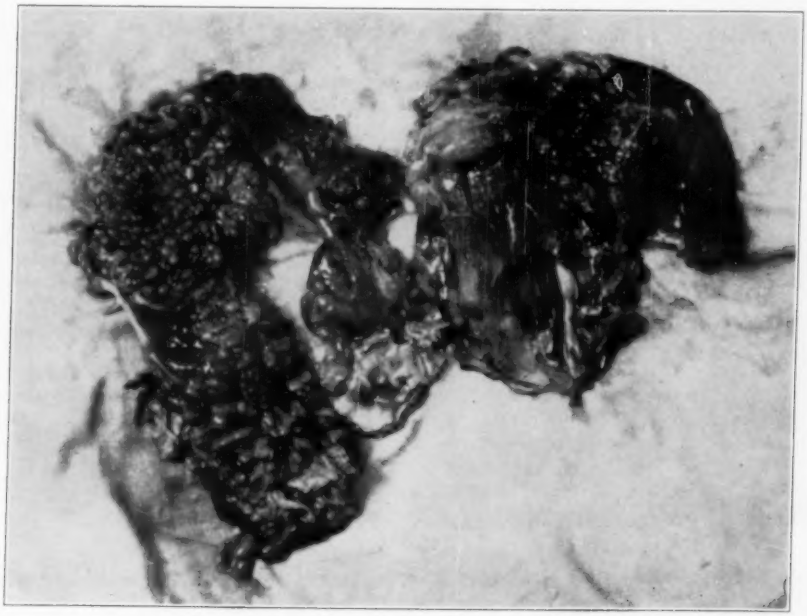

FIG. 4

Photograph of the specimen.

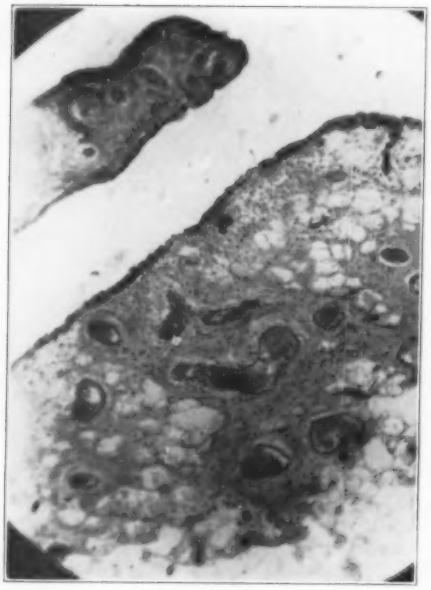

FIG. 5-A

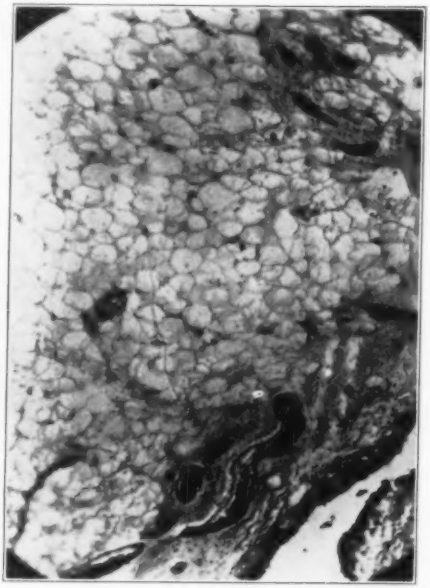

FIG. 5-B

Fig. 5-A: Photomicrograph (× 15) of a villus. This villus consists of fat cells and occasional vessels between layers of connective tissue. A smaller villus is seen at the top.

Fig. 5-B: Photomicrograph (× 15) of a villus showing the dense clusters of fat cells. The deep surface is covered with connective tissue.

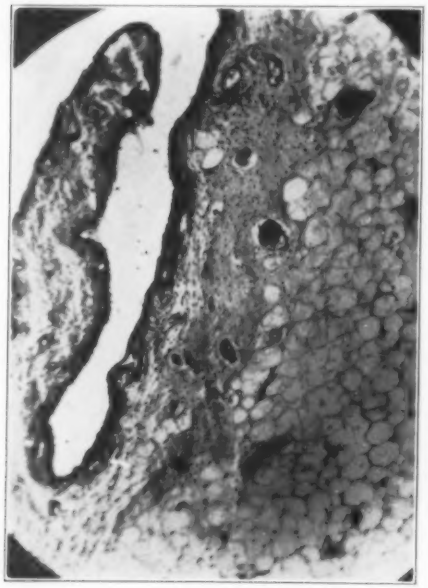

FIG. 5-C

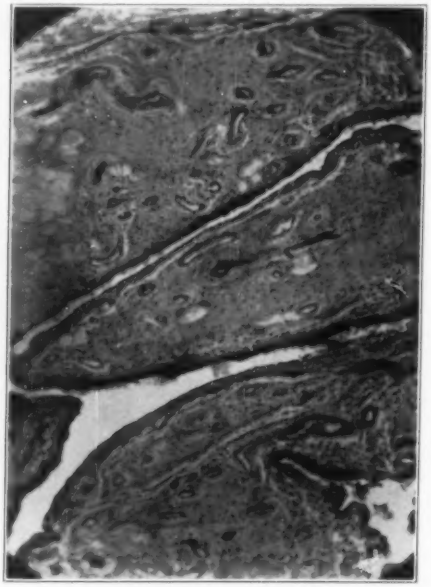

FIG. 5-D

Fig. 5-C: Photomicrograph (× 15) of two villi, one large and one small. There are many fat cells and a few blood vessels, and the deep surfaces are covered with connective tissue.

Fig. 5-D: Photomicrograph (× 15) of villi which consist mostly of connective tissue, blood vessels, and a few fat cells.

The patient was re-admitted on October 9, 1953, and on October 14, a second operation, similar to the first, was performed on the right knee, a medial parapatellar approach being used. The findings were exactly the same as those of the first operation. The menisci were removed because of degeneration. After a normal recovery the patient was discharged on November 3, 1953.

The patient was last seen about five months after the first operation (Figs. 3-A and 3-B). She had no pain, her gait was much improved, and there was no sign of recurrence. In a letter written in August 1954, that is, about a year after the operations, the patient stated that there had been no recurrence of the symptoms and that she could walk quite well.

In another letter written in December 1954, and in a third letter written October 9, 1956, in answer to a questionnaire, she stated that she was extremely pleased with the results. There had been no recurrence of the swelling or fluid accumulation. She could walk well and without pain for reasonable distances but became a little tired if she walked too much. She was on her feet practically all day. In both knees extension was complete while flexion was limited to about 80 degrees. The circumference of the right knee was forty-five centimeters and that of the left was forty-three centimeters. In conclusion she said that all her family and friends were as pleased as she with the results of the operations.

PATHOLOGICAL REPORT

The specimen from the left knee (Fig. 4) consisted of two pieces of the wall of the capsule. One piece was nineteen centimeters long, fourteen centimeters wide, and 0.2 to one centimeter thick. The outer surface was covered with muscle fibers, while the inner surface was covered with villi, these villi being of varying sizes up to two centimeters long. The other piece, which was probably part of the first, was thirty centimeters long, ten centimeters wide, and two to three centimeters thick. Its surfaces were the same as those of the first piece. The villi were yellow in color and of different sizes. Histological study showed that they consisted of dense clusters of fat cells between small numbers of vessels. Over the deep surface of each villus was a thin layer of connective tissue which was infiltrated with lymphocytes and covered with an over-all layer of flattened cells (Figs. 5-A through 5-D). In summary it may be said that the specimen consisted of a thickened joint capsule, the inner surface of which was made up of many hypertrophic villi infiltrated with fat cells.

SUMMARY

The rare tumor, arborescent lipoma, was found in both knees of a nineteen-year-old girl. Prior to operation, the symptoms had been present for ten years in the left knee and for three years in the right knee. There was no recurrence of the symptoms during the three-year period following the operation.

NOTE: The author is indebted to Prof. D. Eleftheriou, Head of the Pathology Department of Athens University, for his assistance in preparing the pathological material.

A Torso Suspension Walker for Children*

BY CAROLL M. SILVER, M.D. AND STANLEY D. SIMON, M.D., PROVIDENCE, RHODE ISLAND

The basic purpose of a walker for children is to provide stability and security in assisting the youngster to walk. If the child needs only minor assistance in this effort, because he has adequate power in his trunk and upper-extremity muscles, the present-day walkers are quite satisfactory.

However, for the youngster with cerebral palsy or recovering from poliomyelitis, whose balance is insecure, the existing commercial walkers are inadequate. When the upper-extremity musculature is poor, the child dangles by his armpits in the "crutch" supports of the walker, risking the complication of a radial-nerve crutch paralysis. The child with extensive muscle weakness caused by cerebral palsy fears the walker because his body is not supported firmly, and as a result his walking efforts are retarded.

At the Meeting Street School for Cerebral Palsy, the authors were impressed by the noticeable improvement in the children's walking and general confidence when the trunk was firmly supported.

Accordingly, a walker was designed to support the trunk securely (Figs. 1 and 2). The child's hands rest comfortably on rubber-topped handles, which are not essential to the child's support. The walker has been found to be much superior to other existing walkers, and the children perambulate in it with confidence and increasing facility.

FIG. 1

FIG. 2

Fig. 1: Side view of the walker in use. Note how the hinged pads grip the trunk snugly, affording security and stability. (The vertical tubes in the rear of the frame are remnants of the original walker frame and have no significance.)

Fig. 2: Front view of the walker in use. It is planned to stabilize the walker so that forward and backward motion, only, will be possible with the front wheels.

* Presented in the Audio-Visual Program at the Annual Meeting of the American Academy for Cerebral Palsy, Chicago, Illinois, November 18, 1956.

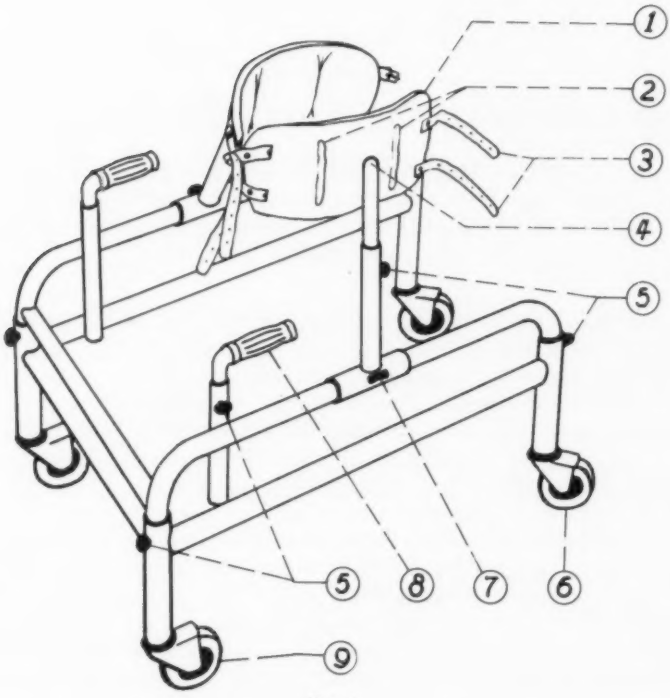

FIG. 3

Diagrammatic drawing illustrating the construction of the walker. (1) Leather-covered hinged pad for trunk support. (2) Leather-covered hinges. (3) Front and rear adjustment straps. (4) Ball-joint attachment on pad. (5) Set screws for adjustment of the walker to the wearer's height. (6) Swivel rear wheels. (7) Thumb screw for horizontal or lateral adjustment. (8) Rubber hand grip. (9) Non-swivel front wheels.

The same construction is of course applicable to an adult walker, although the indications for this are less common.

The basic frame consists of durable aluminum tubing welded together, with four heavy-duty rubber-tired casters. Two lengths of galvanized pipe with smaller pipe telescoped into them are fastened vertically to the frame on either side, to which the padded trunk support is attached by universal joints. A tubular section of aluminum on the frame at the base of each vertical piece is fitted with a thumb screw to permit horizontal or lateral adjustment. Adjustment to the wearer's height is provided by Allen set screws (Fig. 3).

The trunk support is made in two sections, of one-eighth inch 24S-T duraluminum and is hinged to allow close conformity to the wearer's rib cage. It is padded with quarter-inch felt and covered with horsehide. Two leather straps at the front and back fasten it. Hand pieces with ordinary crutch grips are provided at the front of the frame to allow the child to hold on with the hands, if he is physically able to do so.

The new walker has been used for the past six months by patients with cerebral palsy—spastic, athetoid, and "mixed" types. It has proved of definite value and no contra-indications to its use have been found.

COMMENTS ON

The Responsibilities of the Medical Profession in the Use of X-Rays and Other Ionizing Radiation

ISSUED BY THE UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION

The statement issued by the United Nations Scientific Committee on the Effects of Atomic Radiation calls to the attention of the medical profession the fact that a substantial proportion of the total radiation received by man is received in diagnostic roentgenography and roentgen therapy. The Committee recognizes the valuable contribution of the roentgenological profession, through the International Commission on Radiological Protection, in defining the maximum permissible levels of exposure for those who may be occupationally exposed to radiation. These levels of exposure are doses which it appears, in the light of our present knowledge, do not cause detectable somatic injury, and their determination is based on the consideration that the number of individuals concerned is small enough for genetic effects on the general population to be negligible. The Committee considers that the average dose to the germinal tissue of the general population should be limited to about the same order of magnitude as that received from all natural sources (between 0.07 and 0.17 rem per year). It urges that the medical profession minimize the use of radiation, both by avoiding roentgenographic examinations which are not clearly necessary and by decreasing exposure to radiation during roentgenographic examinations. The Committee also seeks the cooperation of the medical profession in estimating the total radiation received by the germinal tissue of the population during the child-bearing age.

The report emphasizes one of the general problems which confronts the physician in the utilization of many diagnostic and therapeutic procedures, namely, the problem of evaluating the beneficial effects of the procedure as opposed to its deleterious effects. The highly publicized accounts of the effects of radiation on the atomic-bomb victims has tended to overemphasize the effects of radiation in general. This, and lack of appreciation of the quantitative aspects of radiation, has resulted in a tendency to place an emphasis on the deleterious effects of radiation which is out of proportion to the actual amount of harm it does compared with the harm done by the other deleterious agents in our environment.

Man has been confronted with other toxic agents in the past. By the accumulation of clinical and experimental information about the quantity of the agents which produce minimal changes, adequate safety measures have been found to control the use of these agents. It is evident that there will be greater utilization of radiation by medicine and industry. The great need is to define more precisely the levels of exposure which will produce minimal effects and at the same time be consistent with the consideration given other toxic agents. The medical profession can contribute to the important task of defining more precisely the maximum permissible levels of exposure by making available information on the effects of radiation to appropriate groups, such as the United Nations Scientific Committee on the Effects of Atomic Radiation.

William B. Looney, M.D.
The John Collins Warren Laboratories of the Huntington Memorial Hospital of Harvard University, Massachusetts General Hospital, Boston, Massachusetts

Proceedings

BOSTON ORTHOPEDIC CLUB

The Boston Orthopedic Club held its first meeting of the year at the Boston Medical Library on October 15, 1956. Dr. R. Glen Spurling [1] and Dr. Robert A. Robinson [2] each spoke on The Diagnosis and Treatment of Acute and Degenerative Lesions of the Cervical Spine.

Dr. R. Glen Spurling stated that the common lesions affecting the cervical intervertebral disc are, in order of frequency:

1. Rupture of the posterior annulus fibrosus with herniation of the nucleus pulposus;
2. Localized osteophytosis of the intervertebral foramina;
3. Cervical spondylosis.

In his experience the disc lesions are the most common. They may be present either lateralward or in the mid-line. The mid-line protrustions are particularly dangerous because of the frequency of spinal-cord compression. The lateralward protrusions involve but one nerve root and, therefore, produce only radicular symptoms.

Localized osteophytosis of the intervertebral foramina is the second most common lesion. It is believed that these bone spurs are the result of disc degeneration, caused by greater than normal stress being placed upon the joints of Luschka.

Cervical spondylosis is the least common but probably causes the greatest degree of disability. Dr. Spurling believes that this lesion starts with degeneration of the disc, followed by bone proliferation and spur formation, involving not only the intervertebral foramina and the posterior portions of the intervertebral disc, but the anterior bodies of the cervical vertebrae as well. This condition is characteristically found associated with similar changes in other parts of the spine, particularly in the lumbar spine. It carries far more serious connotations in the cervical area because of the space requirements of the cervical spinal cord.

While these three lesions appear to occur quite independently, it is thought that perhaps all three of them represent different phases of the same underlying pathological process.

The clinical diagnosis of a lateral-ruptured disc is usually easy, because only one nerve root is involved. On the other hand, the mid-line lesions present a complex set of symptoms and signs, which are extremely variable.

Clinical localization of the laterally placed disc lesion is reasonably accurate, although not nearly so accurate as localization of similar lesions in the lumbar area.

At the fifth and sixth cervical vertebral level the clinical picture is as follows:

1. Reproduction of the pain pattern by means of the neck-compression test;
2. Numbness and tingling involving the radial aspect of the forearm and hand, with numbness and tingling into the base of the thumb;
3. Weakness, atrophy, or fasciculation of the biceps brachialis;
4. Depression or absence of the biceps brachialis tendon reflex.

At the sixth and seventh cervical vertebral level, the clinical picture is as follows:

1. Reproduction of the pain pattern by means of the neck-compression test;
2. Numbness and tingling into the index finger which are aggravated by the neck-compression test;
3. Weakness, atrophy, or fasciculation of the triceps muscles;
4. Depression or absence of the triceps tendon reflex.

Inasmuch as some 90 per cent of all ruptured cervical discs occur at these two levels, it has been difficult to establish the clinical pattern associated with lesions at the other interspaces.

Cervical spondylosis has not received the attention it deserves as a disabling clinical entity. Suffice it to say that any patient with symptoms suggesting degenerative disease of the spinal cord should be considered to have cervical spondylosis until this has been proved not to be so. Because the lesion involves primarily the anterior aspect of the cervical spinal cord, the long tracts are particularly susceptible to damage.

Dr. Robert A. Robinson, in speaking of the treatment of cervical lesions, stressed the fact that the presence or absence of vertebral dislocation or subluxation and of long-tract signs should be carefully determined prior to the inception of any treatment. Patients in whom no long-tract signs are present or in whom no serious progressive clinical nerve deficit is found should first be treated conservatively. This is directed toward posture correction in the thoracic and cervical spine, relief of muscle spasm, and rest of the involved region of the neck.

He described the buckling of the ligamenta flavum posteriorly and the production of osteophytes an-

[1] 332 West Broadway, Louisville 2, Kentucky.
[2] 601 North Broadway, Baltimore 5, Maryland.

teriorly which together may narrow the spinal canal at the level of disc degeneration. When the osteophytes develop on the upriding joints of Luschka laterally, they may intrude on the space in the intervertebral foramina alone, lateral to the cord, and thereby cause nerve-root pressure only.

When disc rupture or large osteophytes cause compression of the cord, he recommended posterior decompression of the spinal cord and section of the dentate ligaments. However, disc degeneration may only cause the occurrence of osteophytes on the upriding joints of Luschka; in this case, the posterior decompression may not, in his opinion, be indicated. From such a level of abnormal mechanics in the cervical spine, brachialgia, neck pain, and pain over the occiput may arise.

Spurs on the facet joints reportedly cause pressure on the vertebral artery with spasm of the artery as a consequence in certain patients. This may be suspected when the patient states that, on turning his head to one side, he has syncope or dizziness. Perhaps, in such patients, one vertebral artery bears an inordinate part of basilar artery circulation. A case in which this syndrome was believed to be recognized and differentiated from Meniere's syndrome was reported. The symptoms were largely relieved by means of a neck brace which prevented motion at abnormal levels of the cervical spine.

A case of post-traumatic progressive subluxation with the presence of neck pain, but with no long-tract signs, was described. Eventually the facet joints in this patient spontaneously fused bilaterally with the involved segment of the neck in the flexed position. When such fusion occurred, relief of pain was obtained.

These cases suggested that in situations when osteophytes irritate or compress nerve roots or irritate the vertebral artery at the time of neck motion, permanent immobilization of the involved cervical level might be the best long-term treatment. Supposedly such immobilization of the involved cervical segment would check osteophyte enlargement and would relieve swelling about the joints at abnormal levels of cervical-spine mobility, such as in the facet joints and in the joints of Luschka. Some patients with extensive osteophytosis throughout the cervical spine, without long-tract signs, have been treated in a cervical collar only even though the signs were severe and total relief could not be obtained by such conservative measures. Such patients were often poor operative risks because of other problems.

With the view that surgical fusion would stop motion at a level of abnormal mechanics in the cervical spine and thus stop nerve-root irritation either classic posterior interbody fusion or, more recently, anterior interbody fusion has been carried out by Dr. Robinson and by Dr. George Smith.

This latter operation has the advantage of stabilizing the neck should subsequent posterior surgery be needed. It has been used chiefly when bilateral nerve-root-compression signs are present at one cervical vertebral level in patients in whom previous laminectomy had entailed the sacrifice of a facet joint. Disc removal through the anterior approach could conceivably relieve the internal turgor of a disc which may be progressively protruding and thus prevent a large posterior protrusion. Fusion of the cervical spine by the anterior approach may be a reasonable way of fusing the involved area after the posterior bone elements have been extensively removed in a previous operation. Dr. Robinson stated that, in general, the postoperative course was less troublesome in patients having had anterior fusion than in patients having had a posterior fusion of the cervical spine.

If there is doubt as to the exact site of the lesion, discography can be done. Examples of discograms were shown.

In the operation for anterior fusion of the cervical spine, the cervical vertebral bodies are approached from the anterolateral aspect in a manner similar to that used by Lahey for removal of esophageal diverticulum. The sternocleidomastoid muscle, the great vessels, and the nerves are retracted laterally and posteriorly, while the trachea and esophagus are retracted medially, thus affording a view of the lower cervical vertebrae. Interbody fusion is then carried out with iliac-bone plugs. This procedure was performed on fourteen patients with promising results. The longest follow-up was almost three years and the shortest follow-up was a little over one year. The method was devised through experimentation on dogs by Dr. George Smith in 1952 and 1953; Dr. Smith and Dr. Robinson have been using the procedure in selected patients since 1953.

The second meeting of the Boston Orthopedic Club was held at the Boston Medical Library on November 19, 1956. A memorial to the late Dr. Osgood was presented by Dr. John Kuhns.

The speaker of the evening was Dr. Leslie V. Rush [1]. Three short motion pictures were shown illustrating the technique of introducing Rush pins into the mid-shaft and supracondylar regions of the femur and in Colles' fracture. Slides were shown illustrating the principles of fixation embodied in the use of these pins, the difficulties and complications experienced in their use, and the means applied to overcome them.

The first motion picture depicted the fixation of a mid-shaft pathological fracture of the femur in a child seven years old. With the patient under anaesthesia, the femur was approached through a short incision between the rectus femoris and vastus lateralis. The vastus intermedius was then split exposing the fracture site over a short area. A second incision was made just proximal to the greater trochanter. Through the

[1] Rush Memorial Hospital, 2208 19th Avenue, Meriden, Mississippi.

second incision a three-sixteenths-of-an-inch pin was driven into the proximal fragment through an opening previously made superior and medial to the trochanter by a guide. The pin was driven into the fracture site and then driven securely into the distal fragment. The proximal end of the pin was left prominent in order to facilitate its removal in seven or eight weeks.

The second motion picture showed the method of fixation used in a supracondylar fracture of the femur through a bone cyst. The patient was a boy, seventeen years old. Most of these fractures are operated upon by the closed method, but in this case, because of the cyst, the open method was used. The femur was exposed medial to the quadriceps tendon and biopsy was done. Two incisions were then made over the lateral and medial condyles through the joint capsule, one inch from the articular edge of the condyles. The guide was directed so as to emerge at the center of the lower fragment and the pins were driven simultaneously until the points emerged. The fracture was then reduced and the pins were tapped alternately driving them simultaneously into the proximal fragment. The distal ends of the pins, the hooks directed away from each other, were bent to conform to the shape of the condylar region of the femur before being driven into place. The capsule was sutured over the heads of the pins in order to prevent retraction. Dr. Rush explained that if one pin is driven home first, the fracture is offset and the second pin will not go in. If two short pins are used, they are apt to be extruded, and if they are too long, the fracture may be distracted. One short pin may be used when only one condyle is fractured.

The third motion picture illustrated the use of the Rush pin in Colles's fracture. Approximately 150 of these fractures have been fixed by this method, and Dr. Rush believes that the best results occur in elderly people. Occasionally, in comminuted fractures, a part-time plaster splint is needed to assist in holding the fracture in position. This method is useful even in comminuted fractures when there is a large radial styloid fragment. With the fracture reduced and held in place by traction on the index and middle fingers, the anatomical snuff-box is opened and the guide is started into the distal fragment. A Rush pin is then directed vertically into the guide hole, at right angles to the bone, angled to the direction of the radius, and driven in. Motion pictures of the patients taken during the follow-up period showed the early range of motion possible with this method.

Successful use of the Rush pin depends upon the principle of three-point fixation, and the farther apart the points are located the better is the fixation. A smooth transverse fracture is inclined to rotate, but an irregular fracture is not likely to do so. Rotation may be prevented by using a longer rod with as much curve as possible and with as great an angle of insertion as is feasible in the circumstances. Dr. Rush pointed out that a straight rod in a tortuous bone will provide several areas of satisfactory fixation, but one must take muscle pull into account. For example, if the slope of an oblique fracture of the humerous below the level of the deltoid insertion is directed proximally and medially toward this insertion, the action of the deltoid will have a tendency to distract the fracture, and healing may not take place.

The use of the pin in unusual, complicated, and difficult situations of non-union and malunion was described. Many interesting cases from the speaker's practice were described for illustration.

News Notes

The next Annual Meeting of **The American Orthopaedic Association** will be held jointly with **The British Orthopaedic Association** at The Shoreham, Washington, D. C., May 11 to 16, 1958.

The next Annual Meeting of **The American Academy of Orthopaedic Surgeons** will be held at the Waldorf-Astoria, New York City, February 1 through 6, 1958.

The next Annual Meeting of the **Western Orthopedic Association** will be held in Santa Barbara, California, October 20 through 24, 1957.

The Seventh Congress of the **Pan-Pacific Surgical Association** will be held in Honolulu, Hawaii, November 14 to 22, 1957. All members of the profession are cordially invited to attend and are urged to make arrangements as soon as possible. Further information and brochures may be obtained by writing to Dr. F. J. Pinkerton, Director General of the Pan-Pacific Surgical Association, Room 230, Young Building, Honolulu, Hawaii.

The Forty-Third Clinical Congress of the **American College of Surgeons** will be held in Atlantic City, New Jersey, October 14 to 18. Surgical Forum Sessions will again constitute an important part of the scientific programs of the Congress.

The next Part II Examination of **The American Board of Orthopaedic Surgery** will be held January 29, 30, and 31, in New York City. The final date for receipt of application is August 15, 1957. Application should be made to the Secretary, Dr. Sam W. Banks, 116 South Michigan Avenue, Chicago 3, Illinois.

The **International Conference of Ultrasonics in Medicine,** sponsored by the American Institute of Ultrasonics in Medicine, will be held at the Statler Hotel, Los Angeles, California, September 6 and 7, 1957. The meeting will be concerned with the biological and physiological principles, as well as the clinical aspects, of ultrasonics in medicine. Further information can be obtained from the Secretary, John H. Aldes, M.D., 4833 Fountain Avenue, Los Angeles 29, California.

The **Mid-Central States Orthopaedic Society, Inc.,** held its Fourth Annual Meeting at the Broadmoor Hotel, Colorado Springs, Colorado, on March 29 and 30, 1957, under the Presidency of Dr. J. Sims Norman, Pueblo, Colorado. Dr. Irvin E. Henderson, Denver, Colorado, was Chairman of the Program Committee, and Dr. James A. Johnson, Colorado Springs, Colorado, was Chairman of the Arrangements Committee. The following papers were presented:

Endoprosthesis of the Hip. Robert Gunderson, M.D.
Unusual Tumors of the Jaw. James Pollard, M.D.
Modern Usage of the 18-8 SMo Steel Bone Bands in Fracture Treatment. Murray E. Gibbens, M.D.
Management of Tuberculous Joints. William Nelson, M.D.
Some Considerations of Femoral-Neck Fractures. James S. Miles, M.D.
Anuria Complicating Orthopaedic Surgery. Foster Matchet, M.D.
Considerations of de Quervain's Disease and Tennis Elbow. Duane M. Kline, M.D.
Observations on Pain. Fred Hartshorn, M.D.
Symposium: Whiplash Injuries of the Cervical Spine. Harry C. Hughes, M.D., Samuel P. Newman, M.D., Herbert R. Markheim, M.D., James A. Johnson, M.D., and Irvin E. Hendryson, M.D., *Moderator.*
Cases of Fibular Transplant. James A. Johnson and Col. J. O'Donnell.
Fractures Involving the Capitellum in Children. James E. Pollard, M.D.
A Helpful New Test for the Diagnosis of Ruptured Disc. Bernard C. Sherbok, M.D.
Preliminary Analysis of 174 Fractures about the Hip Treated at the Colorado State Hospital, 1954 and 1955. J. Sims Norman, M.D., Richard G. Hamill, M.D., Harper Kerr, M.D., Darwood Clader, M.D., and Donald Ping, M.D.

Officers for the coming year are:

President: F. Walter Carruthers, Little Rock, Arkansas;
Vice-President and President-Elect: W. P. Jensen, M.D., Omaha, Nebraska;
Secretary-Treasurer: H. O. Marsh, M.D., Wichita, Kansas.

The Fifth Annual Meeting will be held in Little Rock, Arkansas, in the Spring of 1958, the exact dates to be announced.

Book Reviews

STRESS AND STRAIN IN BONES. Their Relation to Fractures and Osteogenesis. F. Gaynor Evans, Ph.D. Springfield, Illinois, Charles C. Thomas, 1957. $6.50.

Evans has gathered in this small book a wealth of information on biomechanics of bone. As perhaps the outstanding living research worker in the application of material-testing techniques to bone, he is eminently qualified to present an authoritative summary and critique of the available data which he does in a scholarly way.

He begins with definitions and methods and then divides the available data into several sections. Each section is devoted to a summary and interpretation of the information obtained by one method of investigation. The first is anatomico-mathematical. Three major studies of the femur are described in which observations on cross-sectional distribution of bone substance and density measurements provide the basis for an analysis of stress, similar to analyses of stress in beams or other construction materials (for example, the Fairbairn crane *versus* the neck of the femur). Next he describes the experiments with photo-elastic materials, involving models of bones made from plastics which, when subjected to stress, reveal the patterns of stress under polarized light. Illustrations of the patterns are given. Then follows the work done with strain-sensitive lacquers as applied to the long bones and to the skull. Chapters devoted to the magnitude of stress and strain in long bones as determined by extensometers, experiments to show the breaking strength and breaking characteristics of the femur under load, and similar data on pelvis, mandible, and vertebral column are given. Evans then proceeds to discuss the microscopic level of the subject, considering bone as a material rather than as a structural member. The trajectorial theory of orientation of trabecular bone and the discussion of tension *versus* compression in the formation of the trabecular pattern are presented at length. The experimental approach in this subject varies widely and includes attempts to influence this pattern by mechanical means in animals, in addition to analyzing existing natural patterns. The pertinent experimental data on fracture healing, grafts, bone growth, embryonic development, and tissue-culture experiments are given their proper allocation of attention, and a chapter is also included on systemic factors influencing the strength of bone.

The remainder of the book is devoted to data concerning the compression, shearing, and tensile strength of pieces of bone prepared in various ways with varying orientation to the long axis. Torsion, bending, and fatigue strength are also considered.

To my knowledge, all of these data have never been collected previously. Whereas some of the enumeration of numerical data may prove tedious, the end effect of each chapter is to convince the reader that all of the data have been presented with care and understanding interpretation. One criticism of the book is that it does not contain a sufficient amount of background engineering data to enable the medical reader to evaluate adequately the significance of the data given. One would like to know, for example, what variation might be expected in such procedures as testing of the tensile strength of manufactured materials similar in size and shape to the specimens used in the experiments described. A simple statement of what the actual values are for steel, wood, or other materials would be helpful in the understanding of the data. This is a small criticism indeed, compared with the virtues of the book which are: (1) an excellent digest of the data, (2) a good bibliography, and (3) an excellent mechanical approach. This book will prove an excellent reference volume and will incite much wider investigation of this general subject, inasmuch as the deficiencies of the available data are clearly pointed out.

Jonathan Cohen, M.D.

THE LIFE OF HUGH OWEN THOMAS. David LeVay. Baltimore, The Williams and Wilkins Co., 1956. $6.00.

The book begins with a very interesting account of Thomas' bone-setting forebears who first became interested in the healing art as an avocation in addition to their vocation of farming. Hugh Owen Thomas was the fourth generation of these bone setters. His father, Evan Thomas, moved from North Wales to Liverpool and devoted full time to the irregular practice of medicine—running head on into the opposition of the organized medical profession. Evan Thomas' five sons all entered the medical profession and received the current medical education. Hugh Owen's education at Edinburgh, and later London, was influenced by Syme, Lister, Brodie, and especially Hilton, whose *Rest and Pain* became his guide.

Starting practice with his father, Evan Thomas, he left in 1859, in anger and bitterness because of conflict between the bone setter and the physician.

Hugh Owen moved in 1866 to 11 Nelson Street, Liverpool, where he spent his remaining busy life in unremitting labor to alleviate disease and deformity. Although he performed many general surgical operations, fractures, dislocations, and diseases of the bones and joints comprised the bulk of his practice. His mechanical skill in making his own braces and splints was most remarkable.

The author has included some interesting case reports and pictures of Thomas' splints and has commented at length on his publications.

Thomas had very few friends among his British colleagues because of his aggressive and forthright criticisms of their methods, usually justified according to present-day standards.

To an American, it is interesting to read of his orthopaedic friends in the United States. He admired Gibney. He was a firm friend of Bauer, of Saint Louis, and above all, of John Ridlon, who became his disciple and was highly esteemed. Newton Shaffer, of Saint Luke's Hospital, New York, who angrily opposed Ridlon's attempt to introduce the Thomas splint for treatment of hip disease became the target of Thomas' bitter and relentless contempt. All of Shaffer's writings were dissected and tirelessly, vindictively criticized and ridiculed by this overworked and overwrought physician.

Thomas apparently literally wore himself out with long hours of work, endless writing, and emotional stress; he died at the age of fifty-six of pneumonia.

He was beloved by his patients which is what every good physician aspires to. He was esteemed by enough far-seeing colleagues to ensure the perpetuation of his ideas. His contributions to orthopaedic surgery were great—probably the greatest of these was his nephew and heir, Robert Jones, who carried on with greater tact and kindliness the gospel according to Hugh Owen Thomas.

The book is an extremely interesting study of a personality with many facets "all turned on at once." However, the book is not easy to follow chronologically, and an index would have been useful.

Mather Cleveland, M.D.

CONNECTIVE TISSUE IN HEALTH AND DISEASE. Edited by G. Asboe-Hansen, M.D. New York, Philosophical Library, Inc., 1957. $15.00.

The need for an up-to-date volume on connective tissue has been felt for some time. Ideally, it would bring together information obtained by newer methods in diverse laboratories including those concerned with collagen and mucopolysaccharide chemistry, histochemistry, radioactive isotopes, and electron microscopy. This small volume attempts such a synthesis of information relating to areolar connective tissue, specifically not including the more specialized connective tissues such as tendon, cartilage, and bone. Such an attempt is bound to encounter the difficulties of delineation of what should be included and what omitted, and a critical review of the contents indicates that these difficulties have not been surmounted—if indeed they are surmountable. The book does not attempt to be an encyclopaedic source for material relating to connective tissue. It places its emphasis on recent research; and from the list of contributing authors including such as Meyer, Duran-Reynals, and Klemperer, one may infer that the editor attempted to obtain authoritative summaries of recent advances in various fields. The authors named certainly are outstanding and their opinions are well worth reading, even when they are restricted to narrow confines (for instance, as in the case of Duran-Reynals and his chapter on "Spreading Factor") or to general considerations of disease entities (as in the case of Klemperer and his chapter on "Collagen Diseases"). However, the editor has seen fit to include chapters on subjects such as dermatology, arthritis, fibroses due to injury, and ophthalmology, presumably in order to widen the appeal of the book; this fails of its purpose because of the inadequacy of coverage of these respective fields. However, there are no general areas of the subject that do not receive some attention, possibly with the exception of the newer work by Pauling and others on the structure of collagen. Mention must be made of the singular circumstance that no material more recent than 1953 seems to have been included, with the exception of the personal findings of the authors of the various chapters.

Despite these objections, some of the chapters of this book are welcome summaries of the work and points of view of various authors. For non-chemists, it is illuminating to read the careful data of Meyer on the chemistry of the mucopolysaccharides and to contrast this factual account with the interpretations of his work given by others. One good example is the statement by the editor in the introduction concerning the universality of the distribution of hyaluronic acid in connective tissues, which may be contrasted with Meyer's table regarding its actual occurrence and non-occurrence in experimental data. Another chapter which may be singled out for praise is that of McManus on "Histochemistry". The considered and cautious analysis of the possible meanings of popular histochemical staining reactions is given, and one is struck by the enormous difficulties to be encountered in correlating histochemical stainings with actual gross chemical determinations.

A fault of this book which shows itself in many ways is inadequate editorial control of the material. It is quite proper to include variations of opinion by different authors of the evidence on any one topic, but incompatible statements concerning what are supposed to be facts should not pass without comment. Thus, we read the statement that "hyaluronidase has not been conclusively demonstrated to occur in the mammal in locations other than testicular tissue" (page 113), and then "the ubiquitous occurrence of the enzyme hyaluronidase" (page 127). This is only one of the anomalous contradictions which may be found on careful reading.

Therefore, because of its uncertain orientation, its poor organization, and the inclusion of errors because of inadequate editorial supervision, this book, despite a few rewarding chapters, cannot be recommended for general reading.

Jonathan Cohen, M.D.

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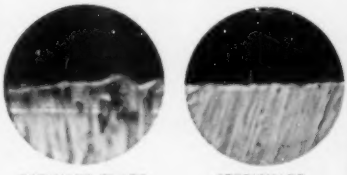

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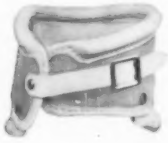

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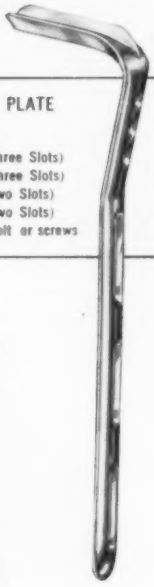

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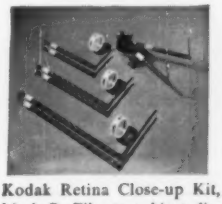

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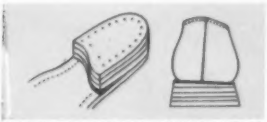

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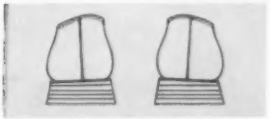

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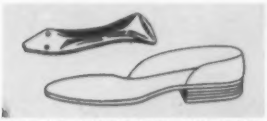

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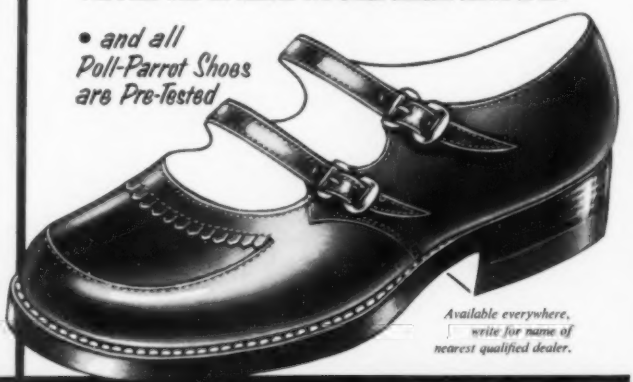

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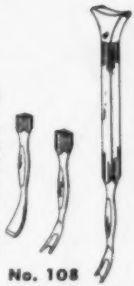

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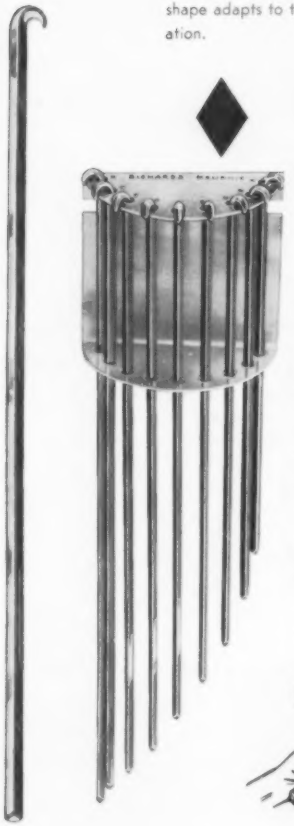

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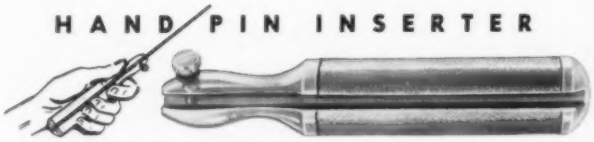

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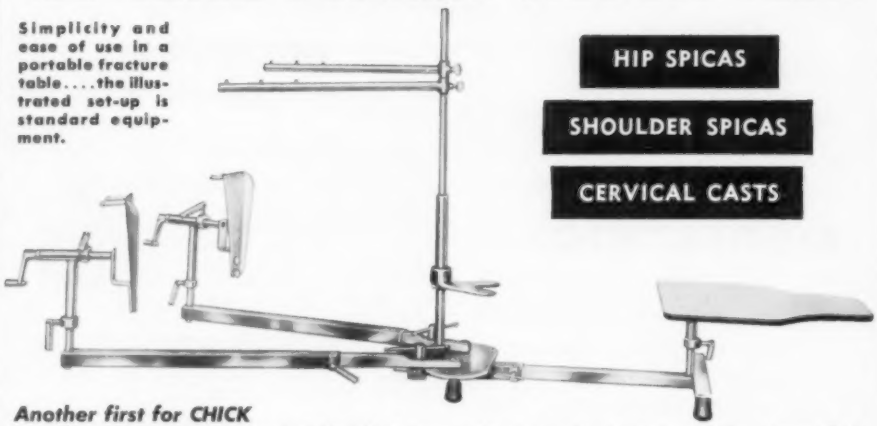

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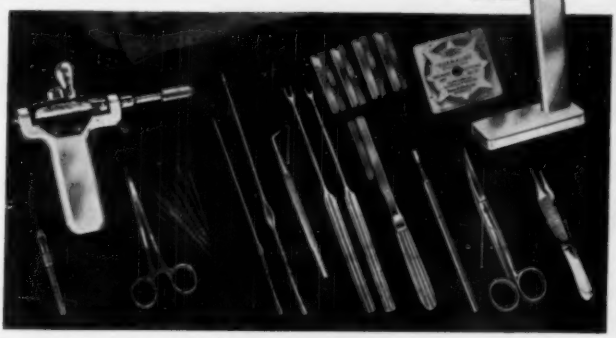

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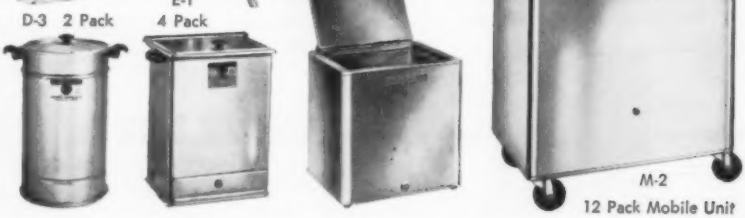

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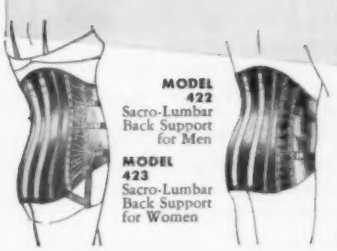

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1910–1911: Vol. VIII, Nos. 1, 2, 3, and 4; August, November 1910; February, May 1911.
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1912–1913: Vol. X Nos. 1 2, 3, and 4; August, November 1912; February, May 1913.
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1926: Vol. VIII (Old Series Vol. XXIV), Nos. 1, 2, 3, and 4; January, April, July, and October.
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1935: Vol. XVII (Old Series Vol. XXXIII), Nos. 1, 2, 3, and 4; January, April, July, and October.
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1938: Vol. XX (Old Series Vol. XXXVI), Nos. 1, 2, 3, and 4; January, April, July, and October.
1939: Vol. XXI (Old Series Vol. XXXVII), Nos. 1, 2, 3, and 4; January, April, July, and October.
1940: Vol. XXII (Old Series Vol. XXXVIII), No. 1; January.
1941: Vol. XXIII (Old Series Vol. XXXIX), No. 1; January.
1944: Vol. XXVI (Old Series Vol. XLII), Nos. 1, 2, 3, and 4; January, April, July, and October.
1945: Vol. XXVII (Old Series Vol. XLIII), No. 2; April.
1947: Vol. 29 (Old Series Vol. XLV), Nos. 1, 2, and 3; January, April, and July.
1948: Vol. 30-A, No. 1; January.

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